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FOREWORD

The Quarterly Bulletin is designed primarily for the information of Canadian industry, universities, and government departments and agencies. It provides a regular review of the interests and current activities of two Divisions of the National Research Council Canada:

the Division of Mechanical Engineering, and
National Aeronautical Establishment, p. iii

Some of the work of the two Divisions comprises classified projects that may not be freely reported and contractual projects of limited general interest. Other work, not generally reported herein, includes calibrations, routine analyses and the testing of proprietary products.

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AVANT-PROPOS

Le Bulletin trimestriel est conçu en premier lieu pour l'information de l'industrie Canadienne, des universités, des agences et des départements gouvernementaux. Il fournit une revue régulière des intérêts et des activités actuelles auxquels se consacrent deux Divisions du Conseil national de recherches Canada:

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Quelques uns des travaux des deux Divisions comprennent des projets classifiés qu'on ne peut pas rapporter librement et des projets contractuels d'un intérêt général limité. D'autres travaux, non rapportés ci-après dans l'ensemble, incluent des étalonnages, des analyses de routine, et l'essai de produits de spécialité.

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THE HOT WORKING BEHAVIOUR OF MAR M200 SUPERALLOY COMPACTS

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ABSTRACT

The hot working behaviour of some hot isostatically pressed low carbon Mar M200 superalloy compacts has been examined by means of axisymmetric compression testing in the range 1050°C to 1200°C at constant true strain rates between 10^{-4} s^{-1} and 1 s^{-1}. The compacts were pressed either below or above the γ' solvus to obtain grain sizes in the range 2-8 μm or 20-200 μm respectively. The fine grained compacts deformed superplastically at all temperatures and at strain rates in the range from 10^{-4} s^{-1} to 10^{-2} s^{-1}. Under these conditions the strain rate sensitivity exponent m was about 0.6. The coarse grained compacts produced peak flow stresses 3 to 6 times larger than the fine grained material and showed a strain rate sensitivity exponent of about 0.12 under the same working conditions. Both the fine and coarse grained materials recrystallized dynamically during deformation leading to flow softening. Uniform recrystallization and deformation occurred in the initially fine grained compacts resulting in high ductility. Localized recrystallization occurred along prior grain boundaries in the initially coarse grained material resulting in localized plastic flow and severe internal cracking at high strains. The manufacturing of powder metallurgy superalloy parts is discussed in the light of these results.

INTRODUCTION

It is widely recognized that powder fabricated superalloy billets have much superior workability than their ingot-produced, as-cast counterparts (Ref. 1). The benefits derive from a reduction of dendritic segregation, with the result that wrought products can be produced from hitherto difficult to work casting-type alloys. Moreover, it has been demonstrated that stable ultra-fine grain sizes can be developed, either in cast and wrought or powder fabricated and wrought superalloys, allowing these materials to deform superplastically (Refs. 2, 3). For example, in the Gatorizing Process (Ref. 4), the superalloy is extruded at a temperature just below the γ' solvus so that adiabatic heating causes momentary solutioning of γ', recrystallization, and rapid re-precipitation of γ' to stabilize the fine, recrystallized and superplastic grain structure. In the superplastic condition, such materials can be forged at low pressures into complex, close tolerance shapes, provided that the working conditions of temperature and strain rate are controlled. The purpose of this paper is to show that the necessary fine grain size for superplasticity can be retained in as-pressed HIP compacts by appropriate control of powder type and pressing conditions.

MATERIALS

The alloy examined was Mar M200, a high strength casting-type nickel-base superalloy which relies on γ' (Ni_3Al) precipitation hardening and solution hardening with tungsten. The master alloy was argon atomized and the resultant powder consolidated by hot isostatic pressing (HIP) in evacuated stainless steel tubes. The powder chemistry and mesh size distribution are given in Table 1.

Four sets of HIP pressing conditions were used as given in Table 2. Since the γ' solvus is 1200°C ± 15°C, HIP 1 represents a two-phase $\gamma + \gamma'$ condition, HIP 2 a partial γ' solution condition, and HIP 3 and HIP 4 full solution conditions. The grain sizes and gamma-prime particle sizes present after pressing are given in Table 2, and selected microstructures shown in Figure 1. The presence of coarse γ' on grain boundaries during HIP treatments 1 and 2 stabilizes the fine as-atomized grain size of the powders (Fig. 1a), while recrystallization to a coarse grain size occurs during the full solution treatment pressings of HIP 3 and 4, Figures 1c and 1d. The compacts can therefore be classified either as fine grained (HIP 1 and 2) or coarse grained (HIP 3 and 4) materials, and their flow and fracture behaviour during hot working are examined accordingly.

TABLE 1

CHEMISTRY IN WEIGHT % AND MESH SIZE OF THE MAR M200 POWDER

Element	Ni	Co	Cr	Nb	Al	W	Ti	Zr	C	B	O_2	N_2
%	Bal	11.08	9.8	1.02	5.23	12.82	2.1	.047	.022	.018	.006	.0014

Mesh	+80	+100	+120	+140	+170	+230	+270	+325	+500	-500
%	.3	4.3	5.5	6.6	9.3	15.6	7.8	8.8	23.2	18.6

TABLE 2

HIP PRESSING CONDITIONS AND MICROSTRUCTURAL CHARACTERISTICS OF THE COMPACTS AT ROOM TEMPERATURE AFTER PRESSING

HIP Sample	Pressing Conditions*	Grain Size μm	γ' Content and Particle Size μm. HF	F	B
1	1050°C/2 hrs/69 MN/m^2	2 - 8		.4	1.5
2	1150°C/2 hrs/69 MN/m^2	2 - 8	.1		2
3	1250°C/2 hrs/103 MN/m^2	20 - 200	.05	.2	
4	1100°C+1230°C/2 hrs/69 MN/m^2	20 - 200	.05	.2	

HF = Hyperfine (spherical), F = Fine (cuboidal) and B = Blocky (irregular).

* All samples air cooled from pressing temperatures.

EXPERIMENTAL PROCEDURE

A high temperature compression testing apparatus was used to simulate hot working conditions. The isothermal axisymmetric tests were carried out between silicon nitride platens in a 10,000 Kg MTS hydraulic testing machine modified for constant true strain rate deformation. The constant true strain rates were obtained by means of an analog function generator designed to operate in conjunction with the MTS controller. This device causes the compression ram velocity to remain directly proportional to the specimen height during straining. Details of the compression train and analog function generator are given elsewhere (Refs. 5, 6). The compression specimens were right cylinders, 9.65 mm long and 6.35 mm in diameter, machined from the HIP bars. The end faces of the cylinders were grooved in order to retain the molten glass lubricants* used to prevent barrelling of the test pieces.

The tests were carried out under flowing argon and at temperature intervals of 50°C in the range from 1050°C to 1200°C. At each temperature, 5 strain rates were used between 3.0×10^{-4} s^{-1} and 1 s^{-1}. In these tests, the specimen height was measured by means of a high temperature displacement transducer which monitored the relative displacement of the compression platens. Developed load and specimen height were continuously recorded on a x - y recorder, or at high strain rates on a high speed 2-channel galvanometric recorder**. The true stress-true strain curve for a given specimen was calculated from the load-displacement data, assuming that no volume change takes place during deformation. The compressed specimens could be quenched within 1 to 2 seconds of the end of deformation in order to retain the hot worked structures for metallographic examinations.

* –200 mesh sodium/calcium boro silicates with varying amounts of magnesia and alumina from Ferro-Industrial Products, Oakville, Ontario, Canada.

** Brush recorder, model 280.

The deformed and quenched specimens were sectioned longitudinally, mechanically polished and chemically etched. Two etching solutions were used, one to reveal γ' morphology and distribution (Inco etch*) and the other to reveal grain boundaries (Marble's reagent**). Examinations were carried out by means of optical and electron microscopy.

RESULTS

The effects of prior thermomechanical history and testing conditions of temperature and strain rate are examined below.

1. Flow Curves

The stress-strain curves of the four compacts were qualitatively similar as shown in Figure 2. Each curve depicts a microstrain region and an apparent macroyield followed by rapid work hardening to a peak flow stress. The peak flow stress is followed by softening where the flow stress falls asymptotically towards a steady state value at high strains. The peak stress, the strain at peak stress and the degree and rate of work hardening and flow softening are dependent on the prior thermal history and microstructure of the compact. The finer the initial grain size, the lower the peak flow stress and the higher the strain at peak stress. Furthermore, the differences in flow behaviour are more pronounced at low strain rates and low temperatures over the ranges investigated.

Under identical testing conditions, the coarse grained compacts undergo considerably more flow softening but take longer to reach steady state as shown in Figure 3. Figure 3b shows that at $\dot{\epsilon} = 1.4 \times 10^{-3}\ s^{-1}$, the coarse grained compacts have not reached steady state flow at strains of 0.8. In the fine grained compacts under the same conditions, steady state is reached much earlier and particularly so at high temperatures. Extrapolating the flow curves of Figure 3b to high strains indicates that the steady state stresses would be similar for fine and coarse grained materials, under similar test conditions, thus demonstrating that the effects of prior thermomechanical history are gradually eliminated during working.

The effects of working temperature are shown in Figure 3. Flow strength diminishes rapidly with temperature in both fine and coarse grained materials, and flow softening is more appreciable at the lower temperatures. The temperature dependencies of the yield*** and peak flow stresses in these compacts are shown in Figure 4 for all strain rates used. The isostrain rate curves show similar trends in both materials particularly at low strain rates. For the fine grained compact (HIP 1), the reversal in curvature observed at high strain rates and low temperatures suggests that the deformation processes may be different to those occurring at low strain rates.

The effect of strain rate is shown in Figure 5 which indicates that all test materials are strain rate sensitive. These and earlier data indicate that thermally activated processes control the deformation over the ranges investigated. The strain rate dependencies of the yield and peak flow stresses at all testing temperatures are presented in Figure 6. The data demonstrate that the fine grained compact is considerably more strain rate sensitive, particularly at the lower strain rates. In this material (HIP 1) the strain rate sensitivity index

$$m = \left(\frac{\partial \ln \sigma}{\partial \ln \dot{\epsilon}}\right)_{T,\ \mathrm{structure}}$$

approximates 0.6 at low strain rates and 0.2 at high strain rates. The gradual transition between the two regions is shifted to higher strain rates with an increase in temperature. In contrast, the strain rate sensitivity index for the coarse grained material (HIP 3) is 0.12 over the entire range. Similar values are obtained using either yield or peak flow stress data. Superplasticity is usually associated with strain rate sensitivity indexes higher than 0.5 (Ref. 7). The important observation, therefore, is that the fine grained compacts deform superplastically under appropriate forging conditions.

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* Inco etch: 50 ml HCl, 25 ml HNO_3, 2 gm $CuCl_2$, 200 ml H_2O.

** Marble's reagent: 10 gm $CuSO_4$, 50 ml HCl, 50 ml H_2O.

*** Defined as the flow stress at a 0.002 strain offset.

2. Processing and hot worked structures

The microstructures depicted in Figure 7 are representative of the structures developed during hot working of the powder compacts. In the fine grained material, for which the testing conditions belong to the high strain rate sensitivity region, the initial grains have been almost entirely replaced by new grains of an even finer size. Under these same conditions, the coarse grained compact shows partial recrystallization localized mainly along prior grain boundaries. The shadowed carbon replicas of Figure 8 indicate that the recrystallized grain size is the same order of magnitude in the two compacts and therefore depends only on the deformation conditions. It increases with temperature and decreases with strain rate over the ranges investigated. Furthermore, it is apparent from these photographs that the recrystallized regions are of a microduplex nature with equiaxed γ and γ' grains uniformly distributed throughout. In view of the short quenching times involved in these tests (<2 s) and of the stability of the hot worked structures when quenching is delayed, the new grains are believed to have formed dynamically during deformation.

A change in γ' morphology occurs during compression and this is particularly evident in the coarse grained materials. The fine (.1 to .4μ) cuboidal precipitates coarsen and transform into oriented plates or rods (1 to 3μ long, .4 to .6μ wide) that are seen in the non-recrystallized areas of these compacts, Figure 8d. The preferred alignment of the precipitates appears to depend on the crystal lattice orientation of the parent matrix and varies from grain to grain in a random fashion. In the fine grained compacts, however, these effects are not so evident since the γ' precipitate prior to compression is already of a coarse size and also these materials recrystallize dynamically to a microduplex structure during compression.

Metallographic examinations indicate that ductility in all compacts increases with temperature and decreases with strain rate. These effects are particularly evident in the fine grained materials in the high strain rate sensitivity region. Figure 7 shows that under identical conditions of strain rate, strain, and temperature, considerably more cracking occurs in the coarse grained than in the fine grained compacts. The important result, therefore, is that hot ductility is greatly improved by the presence of a fine grain size prior to deformation.

DISCUSSION

It has been shown that superplastic flow can be obtained in nickel-base superalloy compacts hot-isostatically pressed below the γ' solvus. Superplasticity is dependent on the fine grain size (Ref. 7) and on the ability of the γ' particles to impede recrystallization and grain growth (Refs. 8,9). This allows the inherent fine grain structure of as-atomized particles to be retained during pressing and prevents the growth of recrystallized grains during forging. It appears therefore that the intermediate extrusion process often used to generate the superplastic condition in superalloy compacts (Refs. 3, 4) is not entirely necessary and that superplasticity can be achieved simply by appropriate choice of powder type, mesh size and HIP pressing conditions (Ref. 10). This is important in practical terms since by HIP pressing to a superplastic condition a costly extrusion process can be eliminated and greater flexibility is allowed in the design of superplastic forging preforms so that forging strains can be minimized. Furthermore, not only are fine grain size and superplasticity important in lowering working pressures, but they also provide for greater ductility during hot working than is obtained with equivalent coarse grained materials (Ref. 10).

The types of powder, mesh sizes and temperature ranges required to ensure the retention of a superplastic condition during HIP processing have not been investigated. However, it is apparent that any powder having a grain size of less than about 10μm should be suitable, provided the pressing temperature is kept well below the γ' solvus (viz. $>25°$C). Examinations in these laboratories (Ref. 10) have indicated that most types of commercial (-60 mesh) argon atomized powder should satisfy the grain size requirements, whereas similar sized powder from the rotating electrode process appears to have grain sizes an order of magnitude larger. Forging these latter compacts in the temperature range close to, but below the γ' solvus would result in non-uniform recrystallization and non-superplastic flow characteristics as discussed below with respect to the present coarse grained compacts. Pressing

above the γ' solvus leads to dynamic recrystallization and, in the absence of powder surface boundary carbide precipitation (Ref. 10), the formation of a coarse grained deformation resistant microstructure.

The flow curves and microstructural observations indicate that, while differences exist in strain rate sensitivity for the coarse grained and fine grained materials, the processes occurring during deformation are qualitatively similar under similar conditions of strain rate and temperature. The restoration mechanisms of dynamic recrystallization and second phase coarsening are operative in these compacts, as expected in nickel-base superalloys (Refs. 11, 12), and their initiation can be associated with the softening process that follows the peak flow stress, as observed in many other materials (Ref. 13). The deformation modes are those of grain boundary sliding and shear strain accommodation by diffusion or plastic flow within the grains (Ref. 14) or, alternatively, those of intragranular flow by dislocation generation, annihilation and rearrangement (Ref. 7). What process is dominant depends on the initial structure, the rate of forming, the temperature and the strain (i.e. the structure).

At slow strain rates, all materials tend to deform by grain boundary sliding, with plastic accommodation within the grains. This is the dominant deformation mode in the fine grained materials both before and after the onset of dynamic recrystallization. In contrast, in the coarse grained material, sliding is at first severely restricted by the lack of plasticity and strain accommodation within the grains which is a consequence of the small grain boundary area and an effective γ' strengthening effect. This restriction of sliding is responsible for the high yield strength and high peak flow stress in the coarse grained materials. However, once dynamic recrystallization is initiated along prior grain boundaries the local deformation mode becomes similar to that of the fine grained material.

At higher strain rates, grain boundary sliding cannot easily accommodate the required deformation rates (Refs. 7, 14). Intragranular deformation by dislocation glide and climb becomes the dominant deformation mode and results in the conventional low strain rate sensitivities. The decrease from $m = 0.6$ to $m = 0.2$ in the fine grained compacts is due to this change in deformation mode. Since the volume fraction of fine recrystallized grains increases with strain, the superplastic properties of all forged compacts can be expected to be greatly enhanced by this structure refinement (Ref. 7) in accord with accepted practices (Refs. 3, 4).

In the fine grained material and at low strain rates recrystallization and deformation occur homogeneously due to the large initial grain boundary area, so that large crack-free strains can be developed under reduced working pressures. The growth of the recrystallized grains is restricted by γ' (Refs. 8, 9) and thus a stable fine grain size is established dynamically during working. In the coarse grained material, the initial intragranular deformation leads to grain boundary distortion and local recrystallization along these boundaries. As in the fine grained materials, the recrystallized grains are prevented from growing to any extent so that the equilibrium grain structure developed during deformation consists of a duplex structure of coarse, non-recrystallized grains in a "matrix" of ultra fine recrystallized material. The new grains are of a similar size to those of the fine grained material deformed under similar conditions of strain rate and temperature.

Observations of the γ' particle sizes and distributions before and after deformation indicate that the recrystallization process involves a local resolutioning of γ' ahead of the advancing recrystallized boundaries. Both theoretical considerations (Ref. 15) and experimental observations (Refs. 15-17) support this contention. This is followed by reprecipitation and growth of equiaxed grains of γ', which occurs when the austenitic matrix reaches some critical degree of supersaturation in the γ' forming elements. The net result is the formation of a microduplex structure comprising discrete equiaxed grains of (recrystallized) γ and (reprecipitated) γ'. Thus any strengthening effect associated with the original γ' distribution is destroyed during working and the soft recrystallized material deforms superplastically at very low stresses.

Deformation occurring after the onset of recrystallization in the coarse grained compacts is concentrated heavily in these soft recrystallized "grain boundary" bands. For any given macroscopic strain, the local strain in these bands is considerably higher than in the fine grained compacts where recrystallization and the soft microduplex structure are more uniformly developed. Also strain accommodation by plasticity within the γ' strengthened interior of the residual coarse grain structure is more difficult and therefore wedge type cracks develop rapidly at points of stress concentration. The net result is that ductility in the coarse grained materials is considerably less than in the fine grained materials under similar working conditions.

The above model implies that the steady state flow stress of the coarse grained materials should be controlled by the structure within the recrystallized bands and that if recrystallization were complete the flow stresses would fall to the steady state values of the initially fine grained materials. While this situation was never reached, because of the early onset of fracture, the flow curves did tend to converge at high strains to those of the fine grained compacts.

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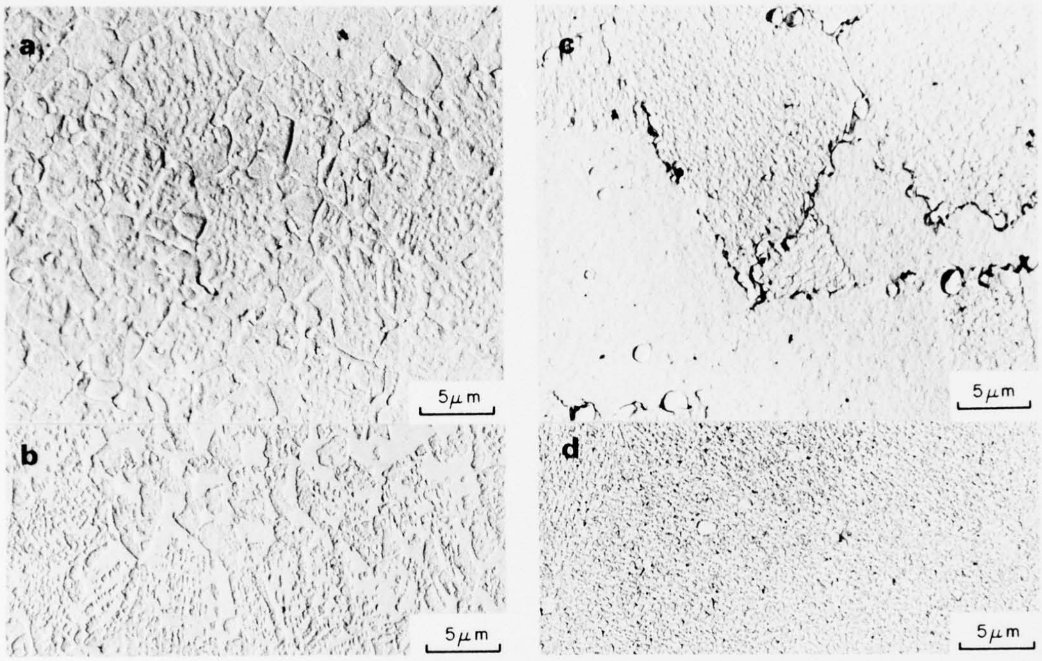
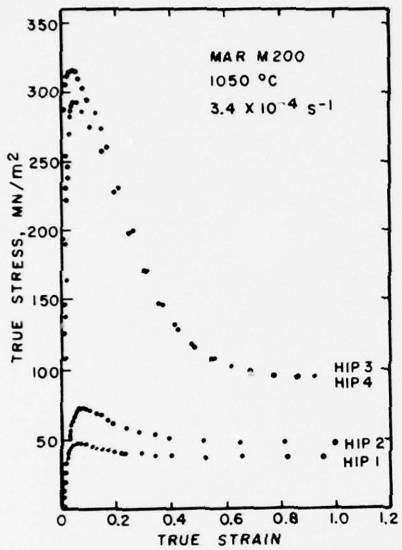


FIG. 1: MICROSTRUCTURES IN MAR M200 COMPACTS. PRESSING BELOW THE γ' SOLVUS (HIP 1) RESULTS IN a) FINE GRAINS AND b) LARGE BLOCKY γ'; PRESSING ABOVE THE γ' SOLVUS (HIP 3) RESULTS IN c) COARSE GRAINS AND d) FINE COOLING γ'. (MARBLE'S ETCH a AND c, INCO ETCH b AND d.)



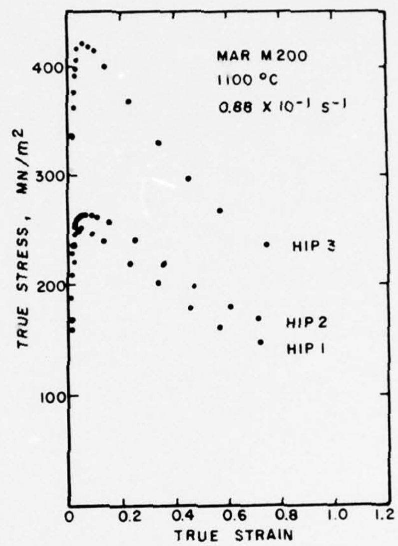


FIG. 2: TRUE STRESS-TRUE STRAIN COMPRESSION CURVES FOR MAR M200 COMPACTS, ILLUSTRATING THE EFFECTS OF HIP PROCESSING CONDITIONS ON HIGH TEMPERATURE FLOW. A) AT 1050°C AND 3.0×10^{-4} s^{-1}, THE COMPACTS PRESSED ABOVE THE γ' SOLVUS (HIP 3, HIP 4) SHOW A FOUR-TO SIX-FOLD INCREASE IN PEAK FLOW STRESS OVER THE COMPACTS PRESSED BELOW THE γ' SOLVUS (HIP 1, HIP 2). B) AT HIGHER STRAIN RATES AND HIGHER TEMPERATURES, THE DIFFERENCES IN FLOW BEHAVIOUR ARE LESS PRONOUNCED.

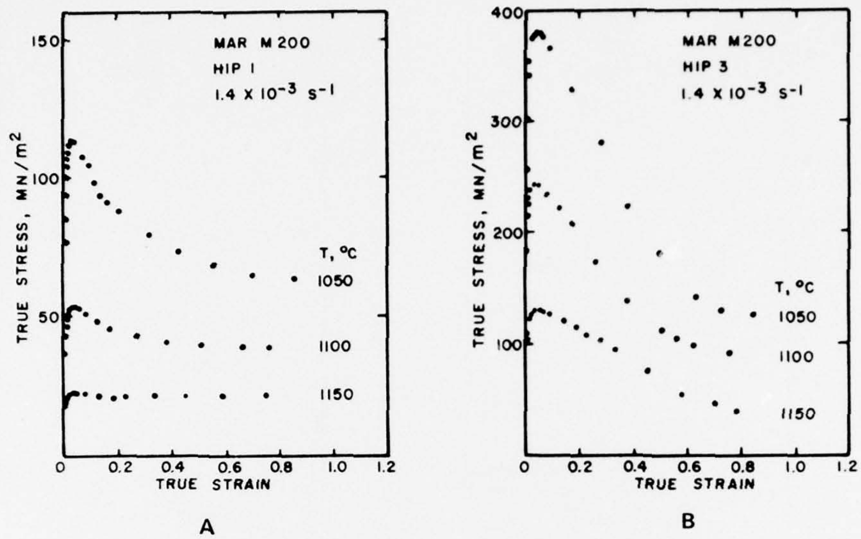


FIG. 3: EFFECTS OF TEMPERATURE AT CONSTANT TRUE STRAIN RATE ON THE COMPRESSIVE FLOW CURVES OF MAR M200 COMPACTS PRESSED A) BELOW THE γ' SOLVUS (HIP 1) AND B) ABOVE THE γ' SOLVUS (HIP 3).

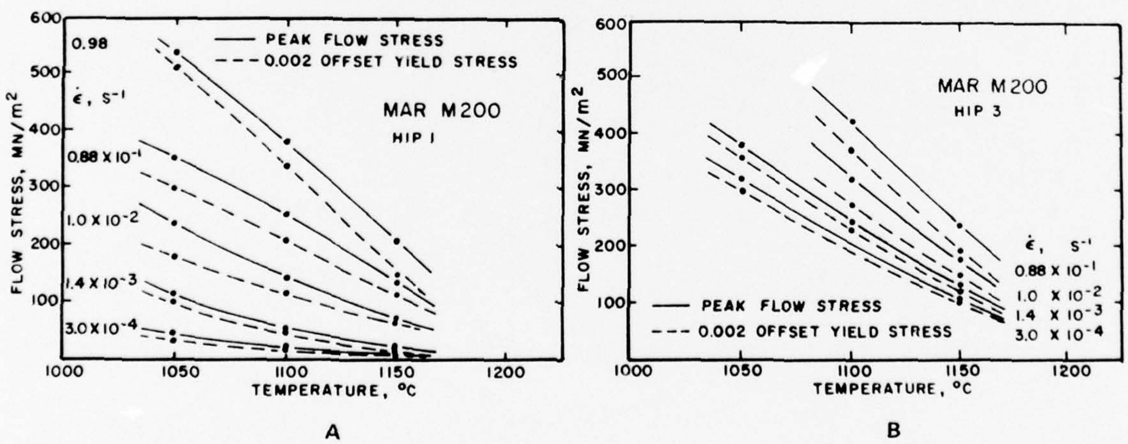


FIG. 4: TEMPERATURE DEPENDENCE, AT VARIOUS STRAIN RATES, OF THE HIGH TEMPERATURE COMPRESSIVE YIELD STRENGTH AND PEAK FLOW STRESS OF MAR M200 COMPACTS PRESSED A) BELOW THE γ' SOLVUS (HIP 1) AND B) ABOVE THE γ' SOLVUS (HIP 3).

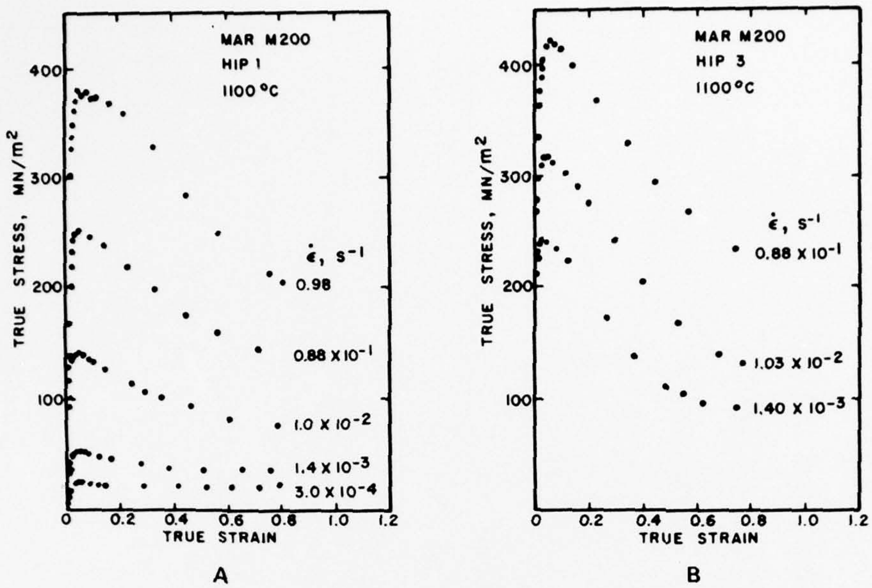


FIG. 5: EFFECTS OF STRAIN RATE AT CONSTANT TEMPERATURE ON THE HOT COMPRESSION FLOW CURVES OF MAR M200 COMPACTS PRESSED A) BELOW THE γ' SOLVUS (HIP 1) AND B) ABOVE THE γ' SOLVUS (HIP 3).

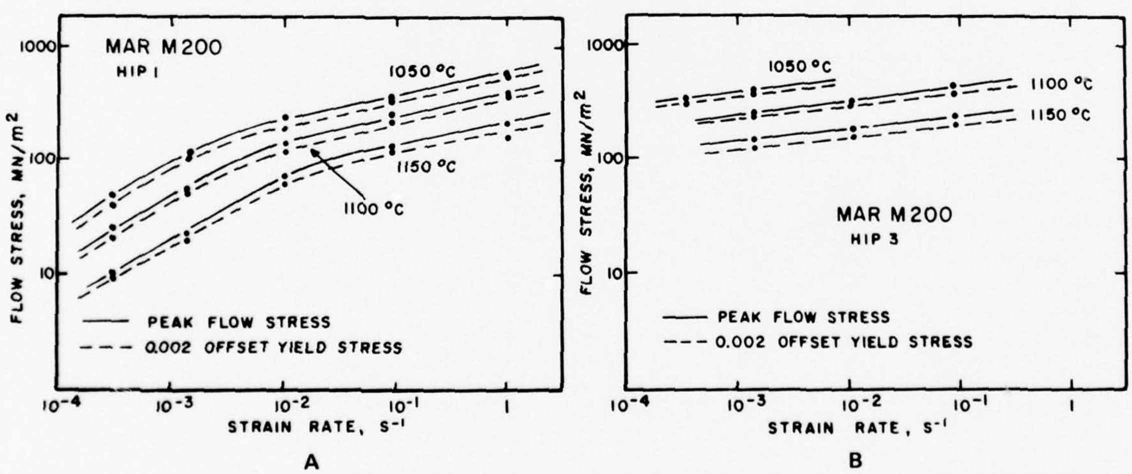


FIG. 6: STRAIN RATE DEPENDENCE, AT THREE TEMPERATURES, OF THE HIGH TEMPERATURE COMPRESSIVE YIELD STRENGTH AND PEAK FLOW STRESS OF MAR M200 COMPACTS PRESSED A) BELOW THE γ' SOLVUS (HIP 1) AND B) ABOVE THE γ' SOLVUS (HIP 3). THE STRAIN RATE SENSITIVITY OF THE FINE GRAINED MATERIAL (HIP 1) IS HIGHER THAN THAT OF THE COARSE GRAINED COMPACT PARTICULARLY AT THE LOWER STRAIN RATES.

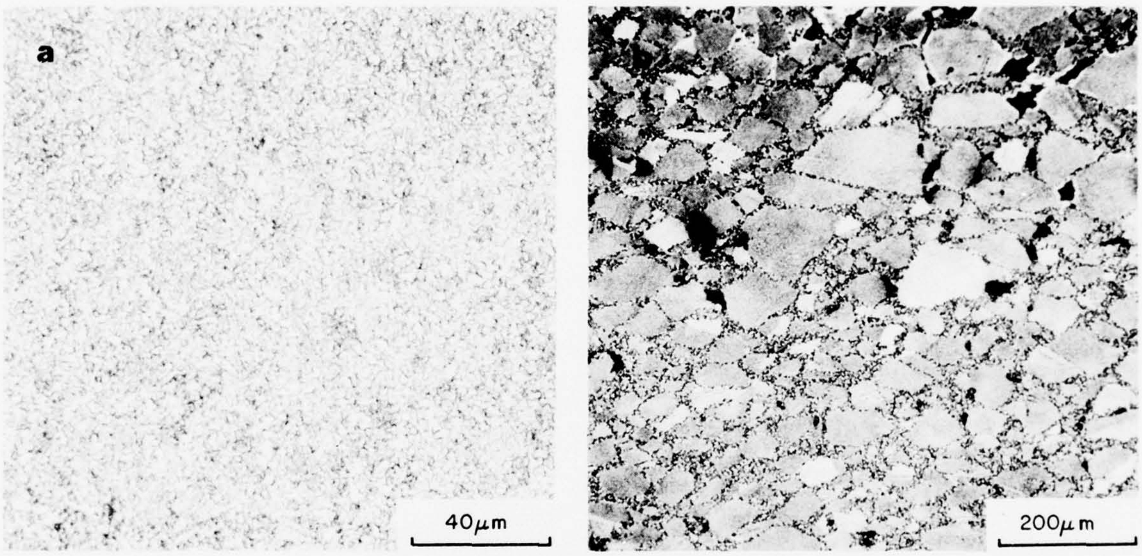


FIG. 7: EFFECTS OF THERMOMECHANICAL HISTORY ON THE MICROSTRUCTURES DEVELOPED IN MAR M200 COMPACTS DURING HOT WORKING TO A STRAIN OF 0.6 AT 1050°C AND 3.0×10^{-4} s^{-1}. SAMPLES INITIALLY HIP PRESSED a) BELOW THE γ' SOLVUS (HIP 1) AND b) ABOVE THE γ' SOLVUS (HIP 3). THE FINE GRAINED COMPACT (HIP 1) IS UNIFORMLY RECRYSTALLIZED WHEREAS IN THE COARSE GRAINED MATERIAL, RECRYSTALLIZATION IS INCOMPLETE AND LOCALIZED ALONG PRIOR GRAIN BOUNDARIES OR TWIN BOUNDARIES.

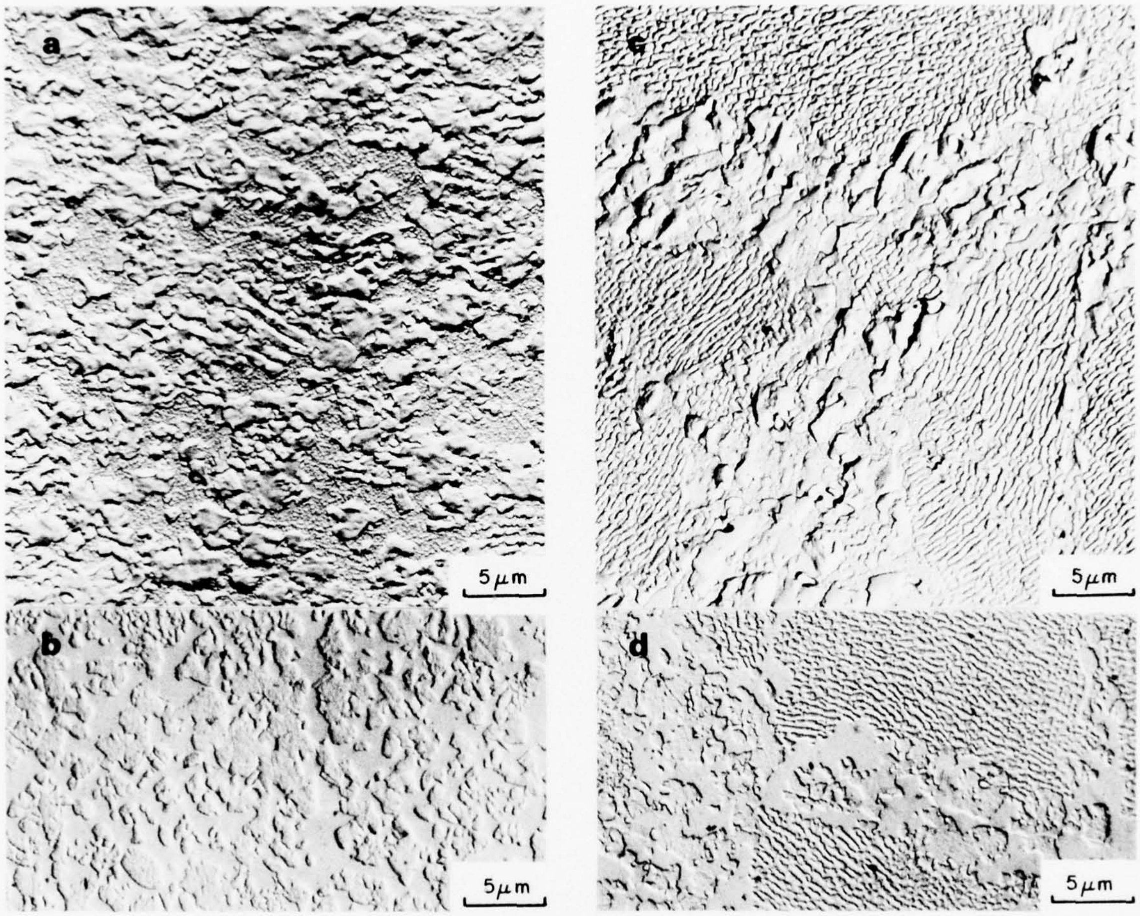


FIG. 8: MICRODUPLEX NATURE OF DYNAMICALLY RECRYSTALLIZED AREAS IN MAR M200 COMPACTS: a) INITIALLY FINE GRAINED COMPACT (HIP 1) ETCHED TO SHOW GRAIN BOUNDARIES AND b) TO REVEAL THE γ' MORPHOLOGY; c) INITIALLY COARSE GRAINED COMPACT (HIP 3) ETCHED TO SHOW GRAIN BOUNDARIES AND d) TO REVEAL THE REDISTRIBUTION AND COARSENING OF γ'.

MATTE ALLOCATION IN A COPPER SMELTER

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ABSTRACT

Methods to improve productivity and efficiency of a copper smelter include mathematical or analytical techniques of the industrial engineer and heuristic techniques of the smelter foreman. An overall procedure is described which attempts to take advantage of the best features of each approach by using an existing interactive computer model of the smelter.

The first step in the procedure is the development of a mathematical description of the steady-state or undisturbed smelter behaviour. Then, based on this description, a problem of matte allocation to the converters to maximize overall matte consumption is formulated and solved. Practical methods for implementing the optimization results are then developed and evaluated by the converter foreman using an existing interactive computer model of the smelter. Finally, these procedures are implemented in the smelter.

This paper describes the first two steps in this work, including a discussion of the results of the optimization study for a specific case.

1.0 INTRODUCTION

In any complex industrial plant, production rates and efficiencies are influenced by the dynamic characteristics, cyclic in some cases, of the individual processing units involved. Copper smelter operation features cyclic or batch operation of the converting and anode furnaces and it is reasonable to expect that overall smelter production and efficiency depends on the choice of cycle times for these interacting processes.

A second feature of such complex industrial operations is that, due to disruptions such as equipment breakdowns or excessive delays due to poor scheduling, these operations seldom operate in a so-called smooth or steady-state condition where a given cyclic behaviour is maintained. Consequently, a two-fold problem exists, first of defining the best steady-state operating procedure for the plant given no disruptions, then determining acceptable procedures for rapid restoration of the best steady-state operation following a disruption.

This paper concerns the first two phases of a project directed at finding possible solutions to this problem for a specific copper smelter at Noranda, Que. (Fig. 1). Phases of the overall project to be discussed include:

(1) Formulation of a so-called steady-state optimization problem using converter cycle lengths and time intervals between converter end points as decision variables.

(2) Solution of this problem using a standard optimization technique.

(3) Evaluation of the feasibility of smelter operation using the optimal cycle lengths and end point spacings.

(4) Determination of procedures by which the plant foremen could restore optimal smelter operation following disruption due to equipment breakdowns and other reasons.

Phases (3) and (4) will each involve two stages. In each case, preliminary evaluations of the proposed procedures will be made by operating personnel and others using an existing interactive computer model of the smelter (Refs. 1, 2, 3). Then, if the operating personnel are satisfied that the procedures are workable, they could be evaluated in the actual plant.

2.0 PROBLEMS OF SMELTER OPERATION AND POSSIBLE SOLUTIONS

The material flow in the converter aisle of a copper smelter is depicted in Figure 2. The major processing units are reverberatory furnaces, converters and anode furnaces.

The reverberatory furnaces smelt copper concentrates to produce reverberatory matte consisting of a mixture of iron and copper sulphides. Matte and reverberatory slag are tapped periodically from the furnaces in order to recover some of the residual copper it contains. Two types of reverberatory furnaces are used in the smelter, the hot charge furnace being fed roasted concentrates and the wet charge furnace receiving concentrates directly from the mill. The matte produced by the hot charge furnace usually has a higher concentration of copper. Ladles of reverberatory matte are transferred via overhead cranes to the converters where the molten matte is subjected to an air blast. The iron and copper sulphides are oxidized to an iron silicate slag and to blister copper in a two-stage batch process which takes about 8 to 10 hours. The earlier slag stage is divided into four to six blowing periods, each starting with a number of matte additions and ending with the removal of a number of ladles of slag which are returned to the reverberatory furnaces. During the second or copper stage, copper sulphide is oxidized to blister copper, with periodic additions of cold copper to absorb the excess heat produced by the exothermic reaction which occurs. Thus, converter operation is cyclic, the cycle consisting of the slag and copper stages with their respective sequences of material additions and removals.

Apart from the blister copper used to produce copper pigs for converter cooling, the blister copper is transferred from the converters to an anode furnace for further refinement to anode copper. The anode copper is tapped to a casting wheel where anodes are formed for final electrolytic refining. The anode furnace operation is also cyclic, consisting of loading, refining and casting phases, with a typical cycle time of 12 hours.

To minimize crane interference, the converter aisle foreman attempts to distribute crane activities evenly over his shift by forecasting and adjusting the timing of the converter end points such that only one converter requires extensive crane service at any one time. However, due to the different sizes and processing rates of the various converters, he attempts to speed up slow converters or to hold back fast ones, to prevent the cycle of one converter overtaking the cycle of another.

Many unpredictable factors such as crane breakdowns, changes in matte composition, changes in converting rates or excessive crane delays due to poor scheduling also interfere with the foreman's efforts to maintain good production rates.

In view of such difficulties, what can be done to assist the foreman to improve operations? As a first step, a smooth, steady-state mode of smelter operation must be defined, in terms of the sequence of events in each converter and anode cycle and of the relative time spacing between these cycles. Currently, the smelter foremen follow a set of general but unwritten operating rules. This mode of smelter operation should be replaced by a clearly defined "ideal" mode to serve as an objective to be sought by the converter foremen. Then, when disturbances occur, foremen can strive to restore this ideal operating condition as quickly as possible, using their own ingenuity.

A second step involves the development of general strategies to restore the "ideal" steady-state operation quickly following a disturbance, while trying to minimize production losses and other costs.

3.0 A METHOD FOR SEEKING IMPROVED SMELTER OPERATING PROCEDURES

Attempts to improve the productivity or efficiency of a copper smelter inevitably encounter a number of practical difficulties, which effectively limit the extent of such improvements. On the one hand, the analytical tools of the systems or industrial engineer are seldom able to cope adequately with the effects of a lack of process and operating knowledge, incomplete and inaccurate data, process disturbances of great variety and frequency and the sheer dimensionality of the decision making task. On the other hand, the experience of on-the-job training permits the converter foreman to implement evolutionary and generally very conservative changes to operating practice which yield gradual or incremental improvements while maintaining an adequate level of smelter performance. In effect, while the converter foreman performs very cautious experiments on the actual smelter to obtain incremental improvements, the systems engineer performs more daring experiments on a mathematical representation of the smelter in attempts to determine that "optimum" operating practice for which smelter performance is theoretically best.

The heuristic approach of the converter foreman is limited not only by the constraints on the scope of his experiments but also by the lack of opportunity to take a global view of the smelter operation due to the pressures of meeting day-to-day production targets and of dealing with his regular administrative duties. The more global analytical approach of the systems engineer is limited by the approximations in his analysis which very often tend to invalidate the procedures he advocates.

In spite of their respective limitations, both approaches have their merits and it would seem that a method which attempts to combine these approaches should produce greater benefits than those derived from application of either method individually. The method described in this paper constitutes one such attempt which makes use of existing analytical and mathematical tools and of an existing interactive computer model of the smelter.

One of the original reasons for developing the interactive computer model of the smelter was to provide the converter foreman with a tool for developing improved converter aisle operating practices without the severe limits imposed on his experimentation in the plant. This smelter model is essentially a speeded-up version of the actual plant which provides on-going simulation results in an easily understood format permitting the foreman to make decisions and to issue commands to the model in a manner similar to actual practice. The key element permitting this interactive operation is a display unit based on a floor plan of the smelter in which colour coded indicator lights and servo driven crane models provide readily understood status information. In addition, converter, reverberatory and anode furnace reports are available on demand on the typewriter or lineprinter in a format designed to the foreman's specifications. References (1), (2) and (3) provide information concerning the nature and application of the interactive model. While this experience has established the value of the model for evaluating alternate smelter practices and configurations, the number of possible alternatives is large and to determine the best procedure, a correspondingly large number of simulation runs would be required. Based on the premise that the number of such simulation trials could possibly be reduced if the procedures suggested by application of optimization techniques were used as guidelines, a general approach was proposed involving the following steps:

(1) Development of a mathematical description of the steady state or undisturbed smelter behaviour.

(2) Formulation and solution of the matte allocation problem to determine the theoretically best sequence of smelter operations.

(3) Development of practical rules for implementing such sequences of decisions in practice and evaluation of their practicality by the smelter foreman using the interactive model.

(4) If the interactive computer model tests indicate the utility and value of the procedures, they can be tested in the actual smelter with an added degree of confidence on the part of the smelter foremen.

4.0 FORMULATION AND NUMERICAL SOLUTION OF THE MATTE ALLOCATION PROBLEM

The general approach focuses on scheduling the converter operations via a matte allocation procedure in order to minimize or eliminate excessive peak demands for crane service and therefore to smooth the matte demand from the reverberatory furnaces and the supply of blister copper to the anode furnaces. Control or decision variables used to achieve such a result include the relative time spacing between individual converter charge cycles and the timing and grade of individual matte additions to each converter. Figure 3 shows a typical converter charge cycle and the sequence of matte additions, slag skims, processing or blowing periods and other events involved in converter operation. The approach involves the following general steps:

(1) Determination of the processing rates of each converter for both wet and hot charge matte.

(2) Matte allocations among converters giving the maximum possible overall production rate for the smelter assuming unlimited matte supply and crane availability.

(3) Determination of blowing sequences for each converter required to process matte allocated to it.

(4) Determination of optimum time spacing between individual converter charge cycles.

(5) Determination of optimum timing of in-blow tasks.

These steps are now considered in more detail.

4.1 Determination of Converter Processing Rates

The processing rate for each converter I can be expressed in terms of T_{HI}, T_{WI}, the average times in minutes to process and handle materials contained in one ladle of hot charge matte, and wet charge matte respectively.

The following operating data is used to determine T_{HI}, T_{WI}:

(1) Weights of a ladle and compositions of hot charge, wet charge matte. Matte is assumed to consist of Fe, Cu, S and gangue or slag forming materials.

(2) Average times to transport matte from the hot charge and wet charge matte tunnels to each converter and to dump them into the converter.

(3) Average times to skim slag from each converter and to transport it to the reverberatory furnaces.

(4) Average times to tap copper from each converter and to transport it to the anode furnaces or the pig bay.

(5) Average air blowing rates and efficiencies for each converter.

The following steps are involved in calculating T_{HI}, T_{WI} for each converter:

(a) Given the matte weight and compositions, the quantities of FeS, Cu_2S and slag added with hot charge and wet charge matte is determined.

(b) Assuming that each converter receives quantities of hot charge and wet charge matte in the same ratio as their respective production rates, calculate the average matte transport addition time for each converter. Note that since the "optimal" ratios of hot charge to wet charge matte as given in Table 3 do not correspond to the matte production ratio, their calculation is based on incorrect estimates of matte transport time.

However, since this time component is not the most significant one and since the average travel time between the hot charge and wet charge matte tunnels is approximately 10 seconds, the error is insignificant.

(c) Calculate the quantities of slag added with and resulting from the processing of hot charge and wet charge matte.

(d) Assuming that slag is returned in equal proportions to each reverberatory furnace, and using operating statistics on the occasions in the converter cycle when it is skimmed, determine the average times to skim and transport the slag produced per ladle of hot charge and wet charge matte added to each converter.

(e) Given the blowing rates and efficiencies, calculate the total processing times in the converter per ladle of hot charge and wet charge matte.

(f) Calculate the time to tap and transport the blister copper produced per ladle of hot charge and wet charge matte.

(g) Determine the total converter time required to process each ladle of hot charge and wet charge matte and to remove and transport the slag and blister copper produced. This calculation produces T_{HI}, T_{WI}, the average time in minutes per ladle of hot charge and wet charge matte processed by converter I.

Results of these calculations are shown in Table 1.

Then, for any converter I, one can calculate an approximate cycle time T_I as follows:

$$T_I = T_{WI} N_{WI} + T_{HI} N_{HI} \tag{1}$$

where N_{WI} = no. of ladles of wet charge matte in converter I
N_{HI} = no. of ladles of hot charge matte in converter I.

4.2 Overall Matte Allocation for Maximum Production

The next stage is to determine the number of ladles of hot charge matte N_{HI} and wet charge matte N_{WI} to be added to converter I such that the overall matte consumption is maximized, subject to various constraints imposed by the smelter operation. In mathematical terms, the maximization problem can be stated as follows:

$$\underset{(N_{HI}, N_{WI}),\, I = 4, 7}{\text{Max}} \quad \sum_{I=4}^{7} (N_{WI} + N_{HI}) \tag{2}$$

Note that the index I has been assigned the values 4, 5, 6, 7 corresponding to the converter numbers used in the actual smelter (Fig. 1).

To maintain steady-state smelter operation, the charge cycles T_I for all converters must be equal. By nature of converter operation, all cycle times can be made equal to some value T minutes only by the addition of a slack or down time ΔT as required. Therefore, if the common cycle time is to be T minutes and the maximum permissible slack or down time ΔT minutes, the corresponding mathematical expressions for these constraints are:

$$T_{WI} N_{WI} + T_{HI} N_{HI} \leqslant T \tag{3}$$

$$T_{WI} N_{WI} + T_{HI} N_{HI} \geqslant T - \Delta T \tag{4}$$

flow characteristics as discussed below with respect to the present coarse grained compacts. Pressing

Matte must be drawn from the hot charge and wet charge reverberatory furnaces in the same ratio as their respective production rates. If the ratio of the production rate of hot charge matte to that of wet charge matte is c, this constraint can be expressed mathematically as follows:

$$\sum_{I=4}^{7} N_{H\,I} = c \sum_{I=4}^{7} N_{W\,I} \tag{5}$$

Converter capacity constraints are expressed as follows:

$$N_{W\,I} + N_{H\,I} \leqslant N_I \tag{6}$$

An integer programming method (Ref. 5) was employed to obtain the numerical solutions to this problem shown in Tables 2, 3.

4.3 Processing of Matte Allocated to each Converter

Having calculated the numbers of ladles of wet charge and hot charge matte, $N_{W\,I}$, $N_{H\,I}$ respectively, to be processed by converter I, and using much of the process knowledge from the first step (Sec. 4.1), it is possible to determine the number of blowing periods in the converter cycles and their start and end times relative to the starting time for the converter cycle. Other details of converter operation are included at this stage which result in modifications to the slack times of Table 3. A simple rule is applied to distribute the demand for each type of matte uniformly over the slag stage blows.

4.4 Determination of the Best Time Spacing Between Converter Cycles

Production delays can arise when crane interference or excessive demands for crane service occur. Effects of crane interference were included in a very approximate way in the analysis and computation leading to the results of Tables 2, 3. The problem of limiting the maximum demand for crane service is considered in this section.

Since demands for crane service are highest at end points of converter blowing periods, the maximum demands for crane service can be minimized by proper choice of the time spacing between starting times for each converter charge cycle. Let t_5, t_6, t_7 be the lengths of time between the start of the cycle for converter 4 and those for converters 5, 6 and 7 respectively. For any given values of t_5, t_6 and t_7, crane demand n(t) as a function of time can be determined by summing the crane demands $n_I(t)$, I = 4, 7 for each converter.

In mathematical terms, the problem is to find the values of t_5, t_6 and t_7 which will minimize the maximum demand for crane service:

$$\min_{t_5, t_6, t_7} \quad V = \max_{0 \leqslant t \leqslant T} \quad n(t) \tag{7}$$

After experimenting with a variety of methods, the minimization was carried out using a method of hill-climbing developed by Rosenbrock (Ref. 6). Only crane demands at end points of converter blows were included, the crane demand being calculated at two-minute intervals over the time T. At time intervals where the minimized crane demand function exceeded two, additional slack or delay time was introduced into the converter charge cycle; the overall cycle time T extended and the minimization repeated. A better strategy is being considered whereby the blow schedules of stage 3 (Sec. 4.3) are adjusted to eliminate demands for more than two cranes without the extension of the converter cycle time T.

4.5 Determination of the Best Timing of In-Blow Converter Tasks

Various additions and removals are made during converter blowing periods where the converter is turned out of the stack only long enough to make the addition or the removal. In most cases, these operations can be performed at any time within a limited time interval, permitting their

deforms superplastically at very low stresses.

execution when cranes are available. Particular in-blow tasks included in this analysis were the addition of matte during slag blows, removal of converter slag during the final slag blow, and the addition of copper pigs for cooling during the copper stage. The same Rosenbrock algorithm was used to determine the best times for executing these in-blow tasks. For the particular operation considered, the timing of 44 in-blow tasks was determined. In cases where in-blow tasks could not be inserted without exceeding the demand for crane service (i.e. where $n(t) > 2$), either slack or delay time was inserted into the converter charge cycle, or, in the case of matte additions, the addition was rescheduled for the beginning of the blow. Obviously, any additions of slack time to a charge cycle invalidate the results of step 4 (Sec. 4.4) requiring that it be repeated after the alternations have been made.

In addition to imposing the constraint that only two cranes are available, the optimization algorithm was asked to minimize the time during which both cranes were in use. This added criterion resulted in the execution of in-blow tasks as much as possible during periods when both cranes were available. As a result, for the example used in this paper, the period of time during which in-blow tasks were being executed and both cranes were in use was reduced from 126 minutes to 78 minutes.

4.6 Discussion of Numerical Results

The following results pertaining to actual smelter operation are presented:

(1) Processing and material handling times for each operating converter, Table 1.

(2) Maximum smelter production capacities for converter cycle lengths of 8 to 11 hours, Table 2.

(3) Allocations of wet charge and hot charge matte to each converter and the converter delay or slack times for maximum smelter production with a converter cycle of 8 hours, Table 3.

(4) Relative time sequencing of converter charge cycles for which peak demand for crane service is minimized, Figure 4.

(5) Typical variations in the demand for crane service with time resulting from application of the optimal guidelines, Figure 5.

Comparing the results of Table 2 with corresponding figures from actual smelter operation, the actual production could, in the limit, be increased by 20-25%. This is a reasonable and not unexpected result, reflecting the relative effects of practical operating difficulties such as breakdowns and scheduling problems on the production potential. Referring to Table 3, converters 4 and 7 receive much more hot charge matte than wet charge matte due to the fact that the combined processing and handling times for hot charge matte in these converters are the lowest. However, although the processing and handling times for wet charge matte in converters 5 and 6 are larger than for converters 4 and 7, converters 5 and 6 receive more wet charge matte. This result may well reflect the imposition of the constraint on the overall ratio of wet charge to hot charge matte consumed by the converters. Table 3 also includes the converter slack or delay times which are very small suggesting the "brittleness" of the results, i.e. even small unexpected disturbances or delays can affect or invalidate the results.

Referring to Figure 4, for maximum production, the charge cycles of converters 4, 5 and 6 should start 245, 390 and 170 minutes after that of converter 7 respectively.

Figure 5 shows the levels of crane service demanded during the time interval 250-350 minutes on Figure 4. Given that these results concern steady-state or undisturbed smelter operation, a number of desirable performance characteristics are noted:

(1) Demand for only one crane during the executions of in-blow slag removals and matte additions during the time interval 270 to 290 minutes.

(2) No crane demands during the interval 320 to 335 minutes, leaving both cranes free for a 15-minute interval to carry out other miscellaneous duties such as bumping ladles, moving pigs from the pig bay to the pig pile, etc.

(3) Total delay or slack times of 6% involving converters 4 and 5.

The slack times of converters 4 and 5 could be eliminated by adding wet matte rather than dry matte to those converters, thus extending their respective blowing periods by about 5 minutes, hence delaying the demands B and H for crane service (Fig. 5). However, if such wet matte additions were made, subsequent demands for crane service would be affected in the following undesirable ways:

(a) Crane service for the copper blow of converter C5 (segment B, Fig. 5) would be delayed by 5 minutes and no cranes would then be available for the previously scheduled skimming of converter C7 during the going high blow period (segment C, Fig. 5).

(b) Crane service needed to start Blow B2 in converter 4 (segment H, Fig. 5) would be delayed by 5 minutes and no cranes would be available to add pigs to converter 5 and matte to converter 6.

While the above analysis illustrates the difficulties arising due to attempts to eliminate slack or converter delays, it is very important to note that the schedule implied by the analysis is much more rigid than that employed in practice. For example, while the analysis is based on a fixed policy regarding the accumulation of FeS in the converter during the slag blowing periods, in practice, converter operators effectively vary this policy to cope with problems such as momentary unavailability of cranes, etc.

These comments illustrate the challenge to be met in the next phases of this project, namely the development of a set of operating rules for the converter foremen and operators which strike a balance between the flexibility needed to make the rules workable and the rigidity needed to achieve more consistent and improved smelter performance. For example, it may well be entirely unrealistic to attempt to preschedule in-blow tasks and perhaps the only possibilities are to maintain fixed and equal converter charge cycles, and to space the converter cycles and blowing periods to smooth out demands for crane service. Furthermore, the previous analysis and the results shown in Table 3 illustrate the unrealistic "tightness" of the operation, suggesting that increased slack times must be expected in practice to accommodate in-plant process and equipment and schedule variations.

As mentioned previously in Section 3, the intent was to make best use of the talents and expertise of the systems engineer and the converter foreman. From the previous discussions in this section it may only be practical to use the converter charge cycle time, the starting times for each cycle and blowing period, and the numbers of wet to hot charge matte for each blow as derived using the analytical methods or guidelines for smelter operation. Within these guidelines, the converter foreman must still make all the detailed decisions in the smelter, using his experience and judgment in coping with random effects such as unexpected breakdowns.

Computation costs to obtain one set of solutions for one cycle time and one set of rules for hot charge and wet charge matte grades are about $100. In practice these costs will depend on the number of trials taken by the user at each step. This number is difficult to predict due to the inherent interaction of the various steps in the computation. In any event, the overall procedure must be employed with great care to minimize computing costs which can be high.

5.0 EXTENSIONS AND APPLICATIONS

The material in this paper derives from work done on a smelter scheduling project up to September of 1975. Further steps are planned for the continuation of this project.

5.1 Model Extension

The problem treated so far is restricted to four specific converters, one large one and three smaller ones, two matte grades and two cranes. To be more useful, the method of solution will be generalized to handle an arbitrary number of different sized converters, several matte grades and any number of cranes.

Interaction of converter and anode furnace cycle lengths as well as reverberatory furnace characteristics will also be considered in order to establish a smooth smelter operating mode. The anode furnaces and casting wheels operate at present with a cycle time of approximately 12 hours. Matte and slag tapping practices in the reverberatory furnaces tend to result in cyclic variations in the bath level. Therefore, it should be possible to find converter and anode cycle lengths and reverberatory slag tapping intervals which are compatible with each other and which permit maximum smelter production.

5.2 Smelter Design Tool

Once the above extensions have been implemented and provisions made to compute crane service times based on arbitrary furnace locations and crane speeds, the method of matte allocations and smelter scheduling could be used as a smelter design tool to help in the determination of good configurations and operating practices for new smelters during their design stages. Problems of component size, location and quantity, material grades and operating practices could be investigated. A similar design tool, treating electric furnace melt shops but with simplified operational complexities and no crane interference, has been developed and applied by Strobele and Corlis (Ref. 7).

5.3 Implementation

A very important aspect requiring more work is the determination of the feasibility of in-plant implementation of solutions found by the methods discussed in this paper.

The first step will be the application of the matte allocation schedule to the interactive computer model of the plant to determine whether it can be implemented by the foreman in terms of simple rules and to determine its feasibility. The amount of randomness in the actual smelter due to variations in processing rates, skim and tap times, etc., will determine how closely one can follow the desired schedule.

The solution found for the example in this paper contains only about 3% slack time, an amount which may not be sufficient to cope with random variations which tend to interfere with the established schedule. Present smelter operation incorporates about 20% slack time. Future analytical studies in conjunction with the use of the interactive computer model will attempt to establish the maximum slack time required and its distribution over the converter cycles, which will accommodate the random effects in the operation and still permit following the prescribed schedule.

After introducing extra slack time into the converter cycles, it may be possible to omit the determination of the exact times for in-blow additions, since the allowed slack time may permit the foreman to decide on the timing of these additions.

5.4 Operation Recovery

Smooth smelter operation is frequently disrupted by unforeseen delays or equipment breakdowns. Even scheduled maintenance tends to create transients in the operation of the smelter. Having established a steady-state operating mode for the smelter, work can proceed towards establishing efficient methods for restoration of this desired mode following plant upsets or disturbances.

6.0 CONCLUSIONS

A practical procedure has been described for allocating matte and scheduling production in a copper smelter, a procedure which permits human intervention in the construction of the schedule. Numerical solutions for an actual plant have been included in which a feasible schedule, never requiring more than two cranes, was produced for the case of steady-state or undisturbed operation. Smelter production corresponding to this schedule can be interpreted as an upper limit and suggests that if one were able to eliminate all random effects, actual production could be increased by 20 to 25%. Procedures are described for developing a practical plant schedule from the results for the ideal undisturbed operation.

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TABLE 1

AVERAGE MATTE PROCESSING AND HANDLING TIMES FOR EACH CONVERTER

Converter		Average Processing Times Minutes/Ladle	
I	Size	T_{HI} Dry Charge Matte (41% Cu)	T_{WI} Wet Charge Matte (32% Cu)
4*	13X30	34	39
5	13X30	35	41
6*	13X30	35	40
7	14X32	32	37

* Equipped with Gaspé punchers

TABLE 2

MAXIMUM REVERBERATORY MATTE CONSUMPTION FOR A RANGE OF CONVERTER CYCLE TIMES

Cycle Time T Hours, Minutes	Total Number of Ladles of Matte Processed
8:00	51
8:30	54
9:00	57
9:30	60
9:55	63
10:25	66
11:00	69

TABLE 3

MATTE ALLOCATIONS TO EACH CONVERTER WITH CORRESPONDING SLACK OR DOWN TIMES FOR A CONVERTER CYCLE TIME OF 8 HOURS

Converter	Wet Charge	Dry Charge	Slack or Down Times (Min.)
4	2	11	0.7
5	6	6	0.2
6	6	6	2.3
7	3	11	1.3

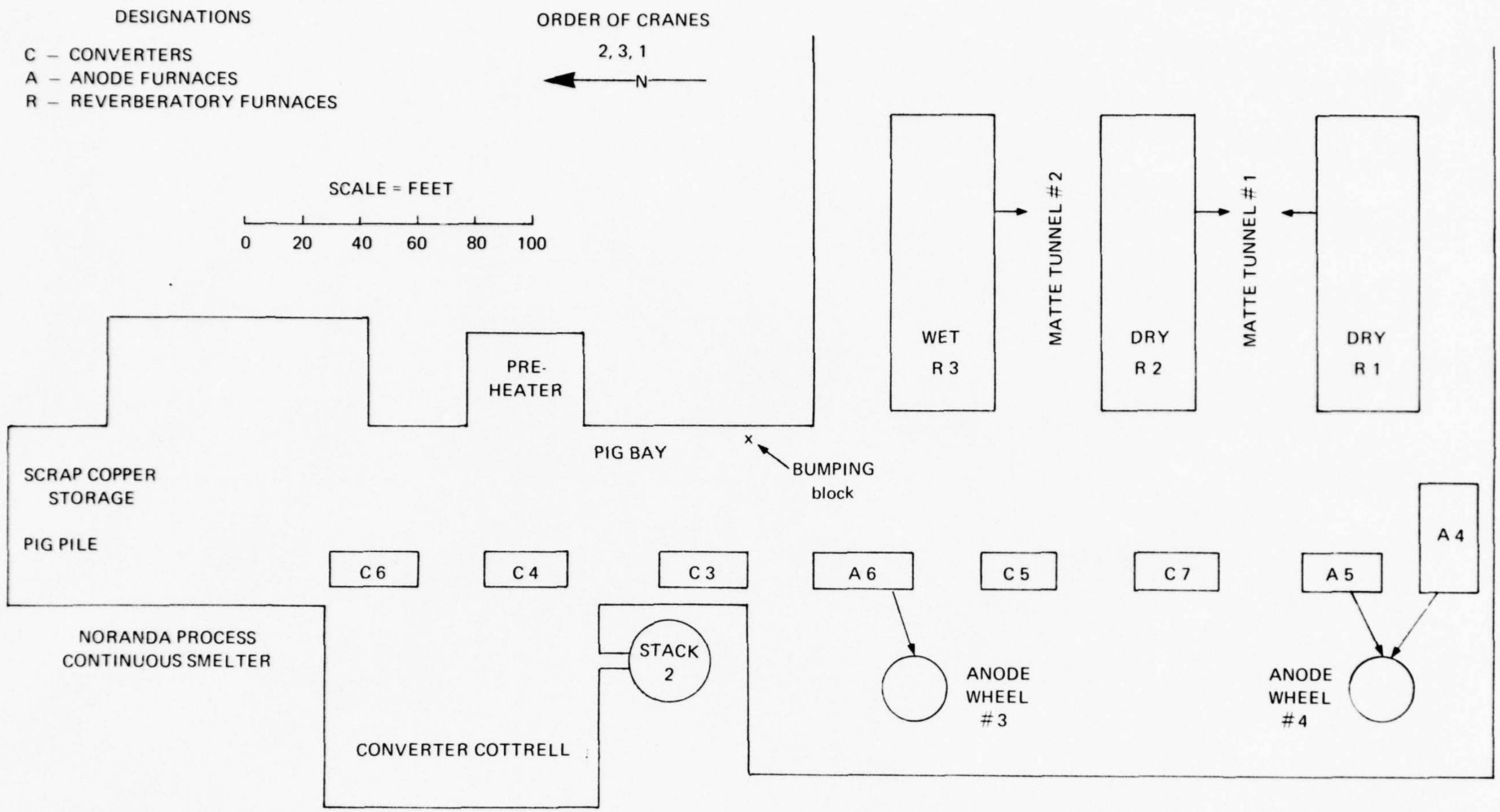

FIG. 1: SMELTER LAYOUT

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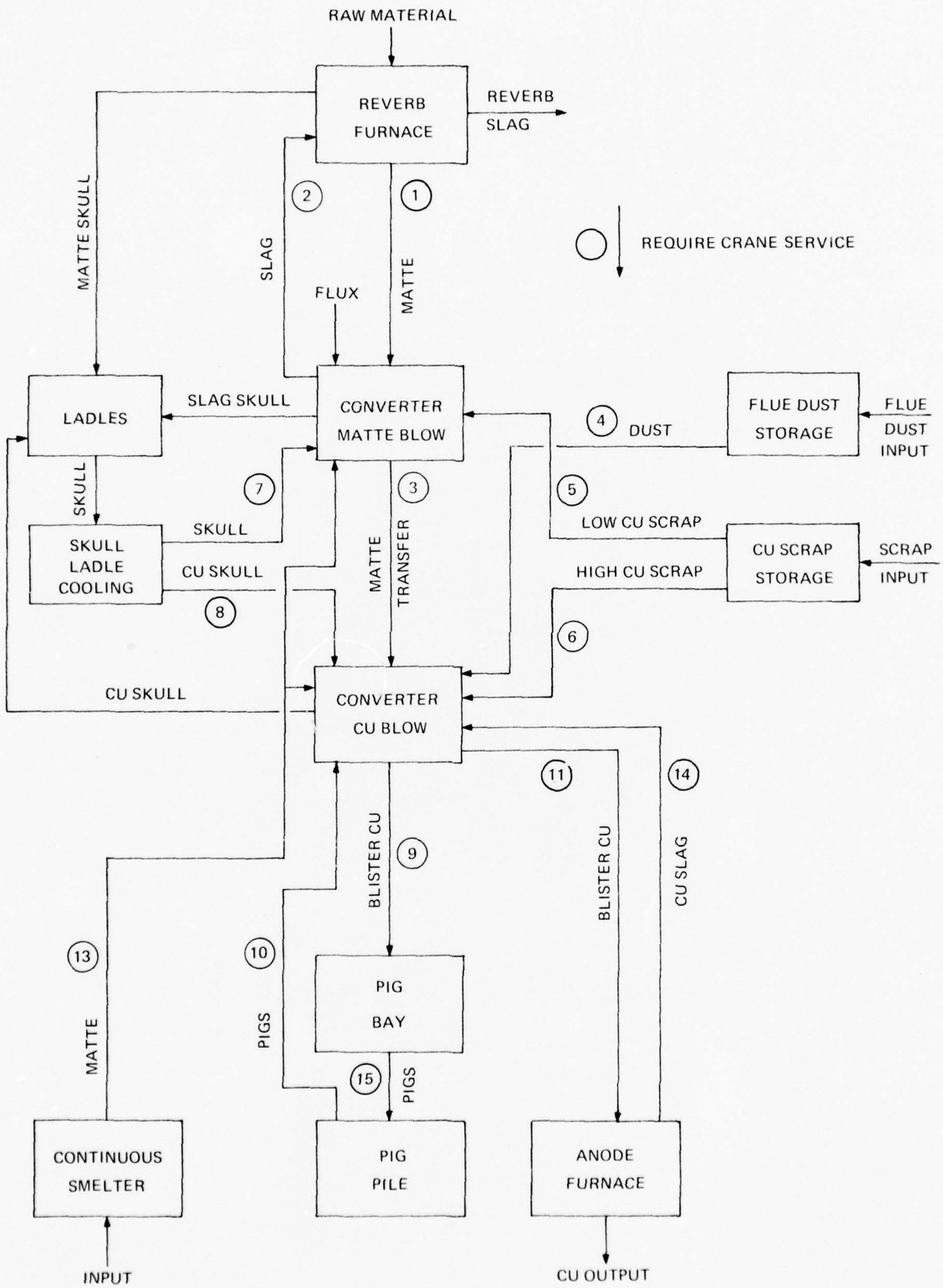


FIG. 2: MATERIAL FLOW CHART

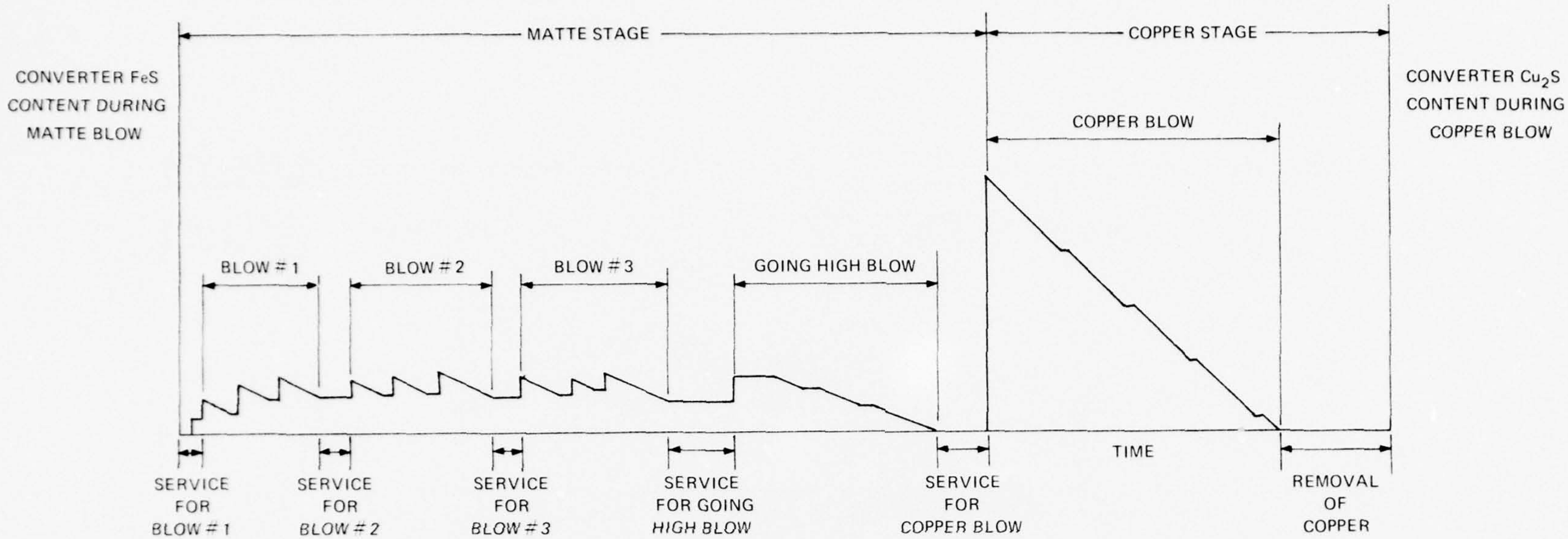


FIG. 3: SEQUENCE OF EVENTS IN A TYPICAL CONVERTER CHARGE CYCLE

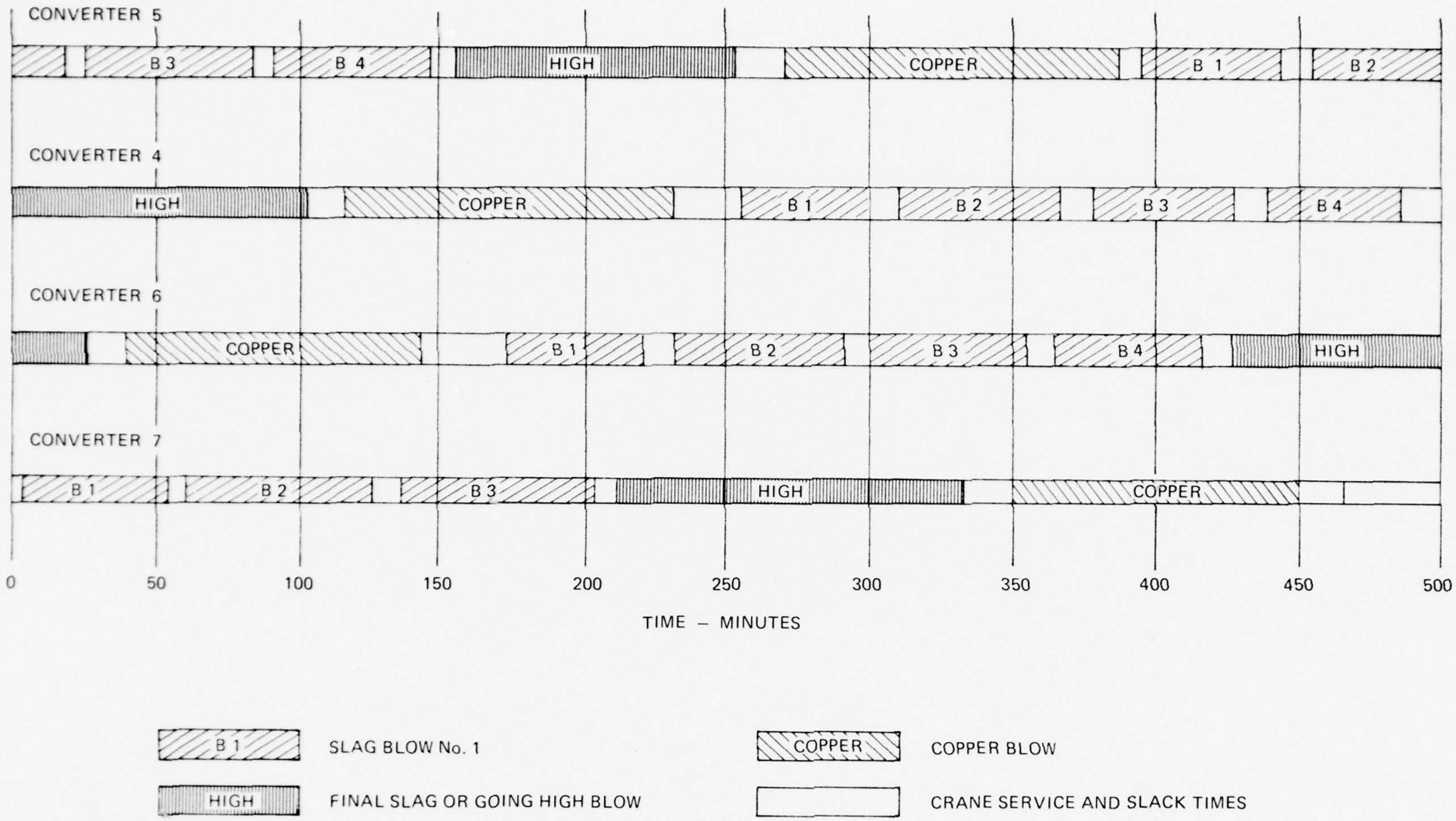
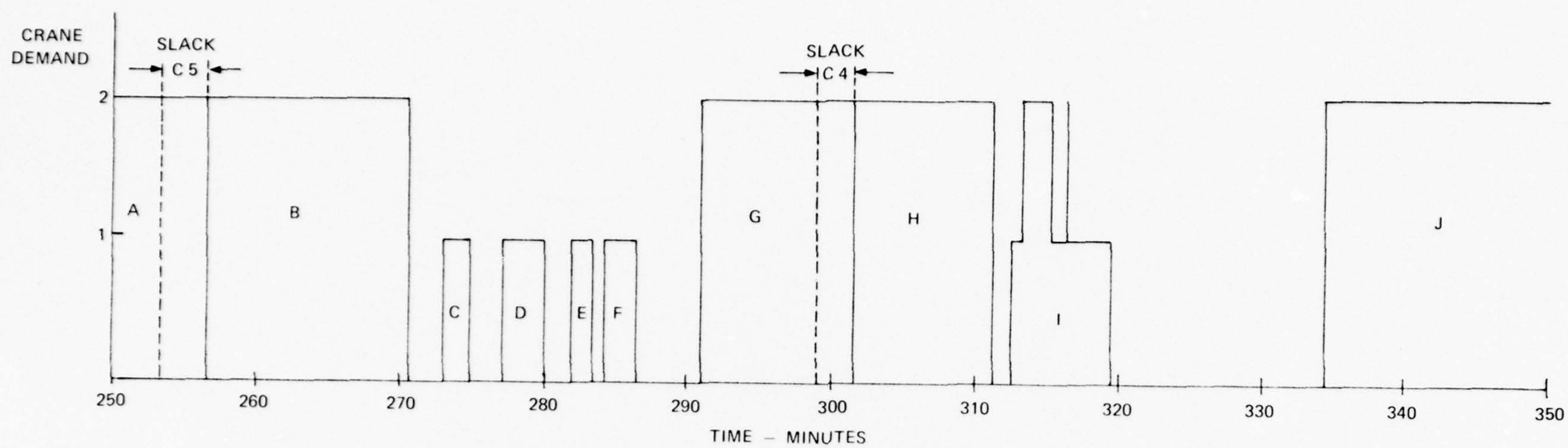


FIG. 4: SEQUENCE OF CONVERTER OPERATIONS FOR MAXIMUM OVERALL PRODUCTION



A: SERVICE TO START NEW CYCLE ON C4
B: SERVICE FOR COPPER BLOW ON C5
C: SKIM DURING HIGH BLOW ON C7
D: ADDITION OF MATTE TO C4 DURING B1
E: PIG ADDITION TO C5
F: SKIM DURING HIGH BLOW ON C7
G: SERVICE TO START B3 ON C6
H: SERVICE TO START B2 ON C4
I: ADDITION OF 2 PIGS TO C5 AND MATTE TO C4 AND C6
J: SERVICE FOR COPPER BLOW ON C7

FIG. 5. DEMAND FOR CRANE SERVICE

CURRENT PROJECTS

Much of the work in progress in the laboratories of the National Aeronautical Establishment and the Division of Mechanical Engineering includes calibrations, routine analyses and the testing of proprietary products; in addition, a substantial volume of the work is devoted to applied research or investigations carried out under contract and on behalf of private industrial companies.

None of this work is reported in the following pages.

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CANADIAN WESTINGHOUSE ENGINEERS USING THE DME HYBRID COMPUTER TO EVALUATE THE CONTROLLER DESIGN FOR A REGENERATIVE GAS TURBINE. HARDWARE CONTROL PANEL WAS USED TO EVALUATE THE SHOP TEST PROCEDURES PRIOR TO THE ACTUAL SHOP TEST TRIALS.

ANALYSIS LABORATORY

DIVISION OF MECHANICAL ENGINEERING

ANALYSIS LABORATORY

AVAILABLE FACILITIES

This laboratory has analysis and simulation facilities available on an open-shop basis. Enquiries are especially encouraged for projects that may utilize the facilities in a novel and/or particularly effective manner. Such projects are given priority and are fully supported with assistance from laboratory personnel. The facilities are especially suited to system design studies and scientific data processing. Information is available upon request.

EQUIPMENT

1. An Electronic Associates 690 HYBRID COMPUTER consisting of the following:
   (a) PACER 100 digital computer
   - 32K memory
   - card reader
   - high speed printer
   - disc
   - digital plotter

   (b) Two EAI 680 analogue computer consoles
   - 200 amplifiers including 60 integrators
   - 100 digitally set attenuators
   - non-linear elements
   - x-y pen recorders
   - strip chart recorders
   - large screen oscilloscope

   (c) EAI 693 interface
   - 24 digital-to-analogue converters
   - 48 analogue-to-digital converters
   - interrupts, sense lines, control lines

2. Hewlett Packard Model 3960 FM instrumentation tape recorder. IRIG standard, 4-track, 1/4-inch tape. Speeds: 15/16, 3-3/4 and 15 inches per second.

GENERAL STUDIES

Study of methods for obtaining a mathematical model of a flexible articulated manipulator arm.

APPLICATIONS STUDIES

In collaboration with United Aircraft of Canada Ltd., a hybrid computer model of an advanced turbo-fan engine is being put together in order to investigate the expected performance of the engine and its control system.

In collaboration with the Railway Laboratory, a pilot hybrid computer model of the NRC roller rig for railway vehicle testing is being built as an aid in the design of the roller rig and its controls.

In collaboration with Aviation Electric Ltd., modeling work is underway in support of their advanced control concepts for both the small business jet engine and the helicopter engine. At present, a validation of a detailed model of a twin engine helicopter model is complete.

In collaboration with the Control Systems and Human Engineering Laboratory and the International Nickel Co., Ontario Division, an interactive computer model of a copper-nickel smelter is being developed to study material handling and scheduling in the plant.

In collaboration with R.L. Crain Ltd., an interactive order streaming program for a print shop has been developed and is currently being evaluated by the press co-ordinators.

In collaboration with Canadian Westinghouse Ltd., and G.F. Crate Ltd., a study is being made of the fuel controller requirements for a new family of 35,000 HP gas turbines. A hybrid computer model is being assembled to be used in the development.

In collaboration with Kendall Consultants Ltd., and SPAR Aerospace Products Ltd., a hybrid computer model of the remote manipulator arm being designed for the space shuttle is being assembled. The model is to include all allowable motions in three dimensions as well as arm flexibility effects.

In collaboration with the Urban Transit Development Corporation and G.F. Crate Ltd., a model of an Intermediate Capacity Transit System is being developed in order to study various system designs and resulting operational performance.

In collaboration with Northern Telecom Ltd., an interactive computer program is being developed to schedule cable orders on cable stranding machines.

CONTROL SYSTEMS AND HUMAN ENGINEERING LABORATORY

INDUSTRIAL CONTROL PROBLEMS

Industrial systems and agricultural applications of fluidic circuits.

Fluid sensor and control component research and development.

Interactive computer modeling applied to operations scheduling of large scale industrial plants and processes.

Development of CAMAC instrumentation for industrial control applications.

Engineering support to specific firms for the implementation of schemes for control and mechanization.

HUMAN ENGINEERING – BEHAVIOURAL STUDIES

Investigation of the control characteristics of the human operator and the basic phenomena underlying tracking performance.

Investigation of the nature of sensory interaction in human perceptual-motor performance.

Investigation of the factors involved in the presentation and processing of information, particularly in relation to simulator design.

HUMAN ENGINEERING – MEDICAL AND SURGICAL

Investigation of the implementation of feedback control in living organisms with particular reference to the control of temperature and pressure in the spinal cord.

Development of heat exchangers for localized cooling of the spinal cord.

Measurement in-vivo of the mechanical impedance characteristics of skin and healed wounds.

Development of models of tissue sections, organs, and whole organisms.

Development of stereo-taxic and allied apparatus for neurosurgical procedures.

PATTERN RECOGNITION AND IMAGE PROCESSING

Investigation of the fundamentals of pattern recognition and their application to identification and classification problems with particular reference to image enhancement and computer analysis of human chromosome material from electron micrographs.

ENGINE LABORATORY

HOSPITAL AIR BED

A hospital air bed designed and built by NRC has been delivered to the Hotel Dieu Hospital in Kingston, Ontario for clinical evaluations of treatment of burn patients. The function and performance specifications of the bed were devised in collaboration with Canadian medical authorities to satisfy Canadian needs.

A second air bed was purchased in England by the Victoria Hospital in London, Ontario, and was adapted by NRC to meet Ontario Hydro requirements.

Several modifications were made to the NRC air bed as a result of the early testing experience. Both beds are being used very successfully for clinical evaluation.

GAS TURBINE OPERATIONS

An investigation of aircraft gas turbine engine operating characteristics is being conducted in conjunction with the Canadian Forces.

Assistance has been given to the Canadian Forces in the development of an inlet protective system for sea-borne gas turbines operating in icing environments.

DUCTED FAN AEROACOUSTICS

A 12-inch diameter ducted fan model has been tested aerodynamically for the purpose of making performance comparisons between a standard 19-bladed stator and a 19-bladed stator with stepped leading edges. Comparative noise studies of the same configurations in an acoustically treated test cell have recently also been completed. Publication is in progress.

These experiments are made by the Engine Laboratory in co-operation with the Division of Applied Physics with the intent of exploring special noise reducing features in ducted fan design.

ENGINE COOLING SYSTEM PERFORMANCE

In collaboration with Canadian industry an experimental study is being made of automotive cooling fan performance with the fan in its actual engine bay environment and subject to normal ram air conditions. The study involves both road and wind tunnel tests at full scale under hot and cold radiator conditions. The test vehicle is typical of an intermediate size North American passenger car, and along with considerable in-vehicle instrumentation, is being provided by the industry for test purposes. Initial road tests have been completed and wind tunnel tests have been started.

ROTOR DYNAMICS

An experimental rig is being constructed to investigate techniques for improved vibration signal diagnosis from rotating machinery under a variety of operating and support conditions.

A review of the published results of analytical and experimental investigations of the dynamic stiffness and damping coefficients of a rotor supported in fluid film bearings is being prepared.

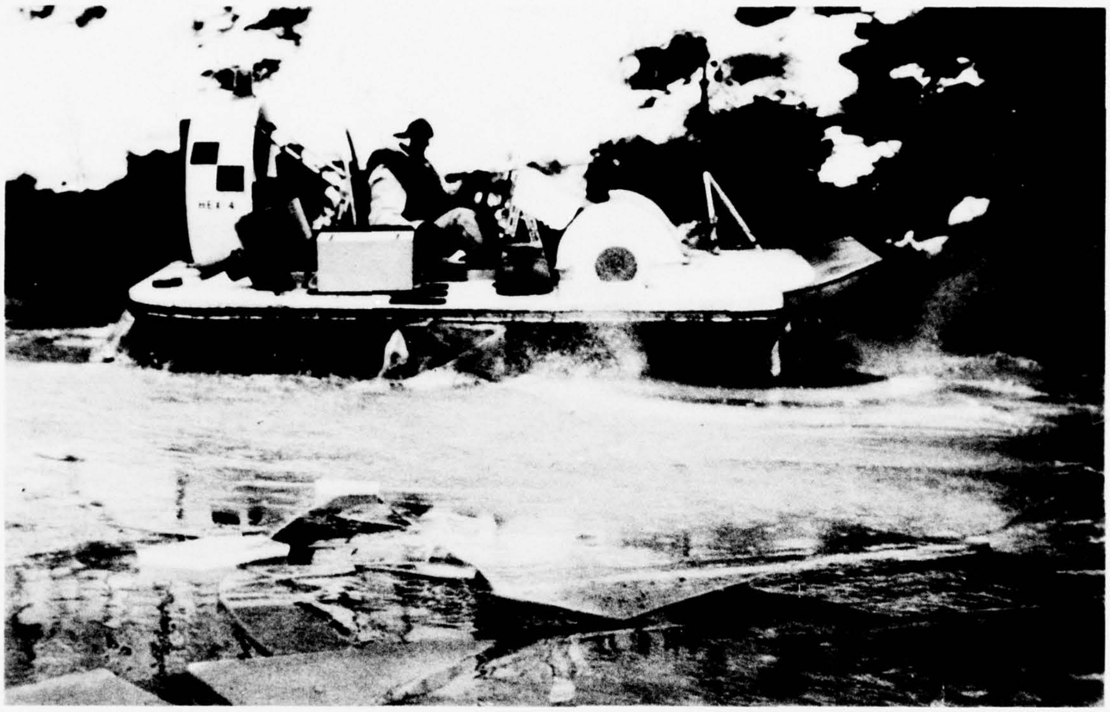
The operating range of the laboratory's torsional vibration transducer calibrator has been extended to meet new requirements from industry. Torsional vibration measurements have been made for the Department of National Defence during field tests of a diesel engine installation. Rotor vibration measurements and analyses have been carried out on behalf of the Department of Public Works and Carleton University.

AIR CUSHION VEHICLES

The first CASPAR program, on the Multicell skirt, has been completed. A report on this program has been issued, and a report on a development of this skirt system is now in preparation.

An analytical study of ACV drag overland is continuing. Advances in the theory have been formulated, and an experimental program is in progress, to explore the validity of these theories and provide numerical values for the coefficients proposed.

An associated study of skirt element structural stability and response to transient disturbances during forward motion is proceeding.



RESEARCH AIR CUSHION VEHICLE HEX-4 ON POND AT UPLANDS TEST SITE, MARCH 1977, CARRYING OUT EXPERIMENTS ON ICE-BREAKING AND OVER-ICE VEHICLE DRAG.

Research vehicle HEX-4 is being used for drag measurement and behaviour studies over snow and ice, related to icebreaking problems. Special instrumentation for this work is incorporated in detachable pods on the vehicle.

HYDROSTATIC BEARINGS

The design and testing of a hydrostatic bearing support system for the railroad roller test rig is in progress.

AEROACOUSTICS

A study of the noise characteristics of centrifugal blowers is in progress. An existing laboratory centrifugal fan has been tested to investigate the relation between flow characteristics and noise generation and to determine appropriate test procedures. The effects of certain changes in casing geometry on the noise generated by a commercial blower have been investigated.

AIR BEARINGS

Experimental and analytical work on air lubricated bearings and seals is continuing. Attention is being focused on aerostatic thrust bearings with one compliant surface.

HYBRID DRIVE VEHICLE SIMULATION

An all-digital computer simulation of hybrid drive vehicles is being developed. A model of the bladder accumulator system is being prepared. Initially, a heat engine-hydraulic drive system will be modeled and verified against a prototype system installed in the Fuels and Lubricants Laboratory. At present, the model can handle a spark ignition engine coupled to an automatic transmission in an automobile.

NRC–PRATT & WHITNEY HIGHLY LOADED TURBINE

The test cell is in an advanced state of preparation and installation of test fixtures is underway. A data acquisition and reduction system has been delivered and will be used on this experiment.

FLIGHT RESEARCH LABORATORY

AIRBORNE MAGNETICS PROGRAM

Experimental and theoretical studies relating to the further development of airborne magnetometer equipment and its application to submarine detection and geological survey, are currently in progress. The North Star flying laboratory has now been retired but analysis of magnetic data taken over east, west and Arctic coasts of Canada will continue for some time to come. Studies are continuing in very low frequency (VLF) and other navigation methods to support long range geophysical surveys. A Convair 580 aircraft to replace the North Star is currently being equipped with new magnetometer and computing systems.

INVESTIGATION OF PROBLEMS ASSOCIATED WITH V/STOL AIRCRAFT OPERATIONS

The Laboratory's Bell 205A1 variable stability helicopter is being employed in programs to investigate terminal area operational problems which are most severe for or peculiar to aircraft capable of low approach speeds. The 205, which is capable of measuring and recording the magnitude of the three components of motion of the atmosphere through which it flies, is employing this capability in a program of terminal area wind and turbulence documentation at the Rockcliffe STOLport. In a related program the 205 is being configured to simulate the flight characteristics and handling qualities of a powered-lift STOL transport aircraft. The effects of severe turbulence and strong wind shears on the approach handling qualities and operational envelope of such an aircraft are being evaluated by flying the simulated vehicle through naturally occurring atmospheric disturbances.

INVESTIGATION OF ATMOSPHERIC TURBULENCE

A T-33 aircraft, equipped to measure wind gust velocities, air temperature, wind speed, and other parameters of interest in turbulence research, is used for measurements at very low altitude, in clear air above the tropopause, in the neighbourhood of mountain wave activity, and near storms. Records are obtained on magnetic tape to facilitate data analysis. The aircraft also participates in co-operative experiments with other research agencies, in particular, the Summer Cumulus Investigation (see below). A second T-33 aircraft is used in a supporting role for these and other projects.

AIRCRAFT OPERATIONS

The Flight Recorder Playback Centre is engaged in the recovery and analysis of information from the various flight data recorders and cockpit voice recorders used on Canadian military and civil transport aircraft. The military systems are being monitored on a routine basis. Civil aircraft recorders are being replayed to investigate incidents or accidents at the request of the Ministry of Transport. Technical assistance is being provided during incident and accident investigations and relevant aircraft operational problems studied.

INDUSTRIAL ASSISTANCE

Assistance is given to aircraft manufacturers and other companies requiring the use of specialized flight test equipment or techniques.

INVESTIGATION OF SPRAY DROPLET RELEASE FROM AIRCRAFT

Theoretical and experimental studies of spray droplet formation from a high speed rotating disc have been conducted. Flight experiments utilize a Harvard aircraft modified to carry external spray tanks. Automatic flying spot droplet and particle analysis equipment is in operation for processing samples obtained in the laboratory and in the field by various agencies. The equipment has potentialities for the analysis of many unusual configurations provided that these may be photographed with sufficient contrast.

AUTOMOBILE CRASH DETECTOR

There is a need for a sensing device to activate automobile passenger restraint systems in incipient crash situations. Investigations are in progress to determine the applicability of C.P.I. technology to this problem.

SUMMER CUMULUS INVESTIGATION

At the request of the Department of the Environment flight studies of Cumulus cloud formations over Quebec and Ontario were instituted during the Summer of 1974. Instrumented T-33 and Twin Otter aircraft with a Beech 18 are being used to determine the properties of Cumulus clouds which extend appreciably above the freezing level. The measurements are being made to assess the feasibility of inducing precipitation over forest fire areas by seeding large cumulus formations. During 1975 a variety of cloud physics instruments were added to the Twin Otter, and special pods for burning silver iodide flares were attached beneath the wing of the T-33 turbulence research aircraft. The effects of seeding on the microstructure of individual cumulus clouds were studied in the Yellowknife area during the summers of 1975 and 1976. This project is planned to continue for several years.

FUELS AND LUBRICANTS LABORATORY

COMBUSTION RESEARCH

Experiments on fuel spray evaporation.

Investigation of handling and combustion problems involved in using hydrogen as a fuel for mobile prime movers.

Study of possible methods for destruction of oxides of nitrogen in engine exhaust gas.

Evaluation of the use of mixtures of methane and carbon dioxide as automobile fuels.

Co-operative studies with Advisory Group for Aerospace Research and Development (AGARD) Working Group 11 to produce a report on aircraft fire safety.

EXTENSION AND DEVELOPMENT OF LABORATORY EVALUATION

Development of new laboratory procedures for the determination of the load carrying capacity of hypoid gear oils under high speed conditions and under low speed high torque conditions.

Evaluation of filter/coalescer elements for aviation turbine fuels.

Evaluation of longlife filter/coalescer elements from aviation turbine fuel service.

PERFORMANCE ASPECTS OF FUELS, OILS, GREASES, AND BRAKE FLUID

Investigation of laboratory methods for predicting flow properties of engine and gear oils under low temperature operating conditions.

Co-operative investigation covering test procedure for the evaluation of thermal oxidation stability of hypoid gear lubricants.

Development of a laboratory method for the evaluation of oil performance in air-cooled two-stroke engines.

Investigation of the electrostatic charging tendency of distillate fuels.

Evaluation of static dissipator additives for distillate fuels.

Evaluation of properties of re-refined oils and by-product sludges.

Investigation of the use of anti-icing additive in aviation gasoline.

Comparative evaluation of Canadian and Russian railroad car journals oils – co-operative program with CPR/CNR and Imperial Oil.

MISCELLANEOUS STUDIES

The preparation and cataloguing of infra-red spectra of compounds related to fuels, lubricants, and associated products.

The application of Atomic Absorption spectroscopy to the determination of metals in petroleum products.

Investigation of the stability of highly compressed fuel gases.

Analytical techniques for analysis of engine exhaust emissions.

Participation in the Canadian (CGSB), American (ASTM) and International (ISO) bodies to develop standards for petroleum products and lubricants.

The design and development of an internal combustion engine/hydraulic transmission hybrid power plant for the energy conserving car.

Further developments of specialized pressure transducers for engine health diagnosis and the development of diagnostic techniques and consultation with licencee in developing production methods for patented transducers.

Evaluation of various products, fuels, lubricants and hardware in respect of their effects upon overall vehicle fuel economy and energy conservation properties.

GAS DYNAMICS LABORATORY

V/STOL PROPULSION SYSTEMS

A general study of V/STOL propulsion system methods with particular reference to requirements of economy and safety.

INTERNAL AERODYNAMICS OF DUCTS, DIFFUSERS AND NOZZLES

An experimental study of the internal aerodynamics of ducts, bends, diffusers and nozzles with particular reference to the effect of entry flow distortion in geometries involving changes of cross-sectional area, shape, and axial direction.

SHOCK PRODUCED PLASMA STUDIES

A general theoretical and experimental investigation of the production of high temperature plasma by means of shock waves generated by electromagnetic and gasdynamic means, and the development of diagnostic techniques suitable for a variety of shock geometries and the study of physical properties of such plasmas.

NON-DESTRUCTIVE SURFACE FLAW DETECTION IN HOT STEEL BILLETS

An eddy-current surface flaw detector is being developed, using a special coil system by which a three-phase modulated R.F. signal is being electrically rotated round the billet at a rate given by the modulation frequency. The system displays the angular position of the flaw on a polar oscilloscope sweep or numerically, while the signal amplitude represents the depth of the flaw.

HIGH PRESSURE LIQUID JETS

High speed water jets generated by pressures in the range of 1000 to 60,000 psi can be used for cutting a wide variety of materials, e.g. paper, lumber, plastics, meat, leather, etc., and for cleaning surfaces such as masonry, rocks, tubular heat exchangers, etc. Nozzle sizes, depending on the application, are in the range from 0.002 to 0.15 in. diameter. A technique for manufacturing small nozzles in the range 0.002 to 0.015 has been developed using standard sapphire jewels available from industry. Larger orifices are manufactured and polished using standard shop procedures.

At present, the following investigations are active in the laboratory:

1. Intensive development of a rotating seal designed and developed in the laboratory. It appears to have great potential, especially for industrial cleaning, quarying and possibly for drilling operations.

2. Experiments on the fracturing of rocks using continuous and cavitating jets.

3. Experiments for clearing ice off runways and for cutting through thick ice ridges.

4. Experiments on the production of intermittent jets with high stagnation pressures.

HEAT TRANSFER STUDIES

Initial development of a temperature control thermosiphon for an electronic package has been successfully concluded. Life testing of this device has commenced.

COMPUTATIONAL FLUID DYNAMICS

To support the experimental work, numerical simulations are being developed in three areas.

Single-pulse jets from vertically-accelerated liquid-filled rotating cones. This is a two-dimensional, axisymmetric, unsteady, incompressible flow problem with a free surface, where the liquid is subjected to large body accelerations.

Fluid dynamics of laser-produced plasmas. The phenomena are considered as two-dimensional, axisymmetric, unsteady, compressible flow problems in which real gas behaviour is considered. The approach, which uses Langrangian formulation, has been used to calculate two cases:

(a) The fluid dynamics of a laser breakdown plasma, with the objective of explaining the mechanism of beam re-entry into the plasma when beam intensity is reduced.

(b) The interaction of a CO_2 laser beam with magnetically confined plasmas. This major problem is currently being studied numerically as part of a co-operative effort with the Aerospace Research Laboratory of the University of Washington.

Shock dynamics and fluid dynamics resulting from synchronized spark discharges on the axis and discharges on the perimeter of a cylindrical vessel containing hydrogen, to achieve high gas temperatures on the axis of the vessel.

GAS TURBINE BLADING STUDIES

A program on the theoretical and experimental study of the performance of highly loaded gas turbine blading has been undertaken as a collaborative program with industry and universities.

INDUSTRIAL PROCESS, APPARATUS, AND INSTRUMENTATION

There is an appreciable effort, on a continuing basis, directed towards industrial assistance. This work is of an extremely varied nature and, in general, requires the special facilities and capabilities available in the laboratory.

Current co-operative projects with manufacturers and users include:

(a) Flow problems associated with industrial gas turbine exhaust systems (Foster Wheeler).
(b) Combustion studies for industrial gas turbine applications (Westinghouse and Rolls-Royce).
(c) Application of thermosiphon as an energy conserving device in industrial applications (Dept. of Agriculture, Ministry of Transport and Farinon Electric).
(d) Scaled model studies on steel and copper converters to establish relative performance and ceramic liner deterioration rates (Canadian Liquid Air and Noranda).
(e) High pressure water jet applications in industry (High Pressure Systems Ltd.).
(f) Power turbine nozzle vane studies (Westinghouse).
(g) Scaled model studies to establish the performance of complex industrial flue systems with a view to establishing specific design and performance criteria.

HIGH SPEED AERODYNAMICS LABORATORY

RENEWAL OF THE TURBULENCE DAMPING SCREENS IN THE 5-FT. × 5-FT. WIND TUNNEL

In more than 14 years of use, during which it has been operated more than 19000 times, the 5-ft. × 5-ft. blowdown wind tunnel has incurred failures in various components, notably the turbulence screens.

Owing to the impossibility of replacement without major dismantling of primary structure, successive removals of ruptured turbulence damping screens have culminated in a situation where the working section flow quality is only marginally acceptable. Four of the original seven screens have been removed.

The full complement of screens will be restored in a rebuild of the settling chamber later this year. In addition the substitution of a more flow restrictive second baffle in the wide angle diffuser, for the existing one, will be made. This will result in a reduction of the destructive turbulence in the flow entering the settling chamber, which, with an improved means of suspending the turbulence damping screens should give an increase in the working life for the replacement screens. Significant improvement in test section flow quality is also expected. The strip and rebuild is scheduled for the quarter June-August 1977.

SETTLING CHAMBER STUDY IN 5-IN. × 5-IN. WIND TUNNEL

Revisions to the settling chamber of the 5-ft. × 5-ft. wind tunnel are under consideration to improve the flow distribution and to decrease the level of pressure fluctuation at the entry to the stilling section. Model tests are being conducted in the NAE pilot facility, to determine the effect of increasing the resistivity of the second porous (disked) baffle in the wide angle diffuser ahead of the stilling section, and the installation of a "trimming" screen at the exit of the acoustic baffle geometry.

TWO-DIMENSIONAL TRANSONIC FLOW STUDIES

Efficient computer programs based on finite difference procedures are available for the design of supercritical airfoils and for the analysis of supercritical flow. The possibility of using finite element methods are being explored with the aim of extending into three-dimensional flow cases.

HIGH REYNOLDS NUMBER PIPE FLOW

This investigation is carried out at the request of and in co-operation with Laval University, Quebec.

The object is to obtain turbulent skin friction data at very high Reynolds number (Re_d up to 20×10^6) in an 8-in. pipe. The investigations to date include calibration of a range of Preston and razor blade surface pitot tubes and mean velocity traverses. Turbulence and noise measurements are also being considered. Analysis of the Preston tube calibration data has been carried out and the results agree well with semi-empirical theory based on the logarithmic wall law.

A floating element balance has recently been supplied by Laval University and will be installed for direct skin friction measurements.

THEORETICAL AND EXPERIMENTAL STUDY OF JET NOISE

Further investigations of internal noise in a low speed jet are in progress. More detailed studies of the interaction of the transmitted sound with the jet flow and some statistical investigation of the multiple wave scattering by the turbulent eddies will be carried out. Some experiments on co-axial jets have been performed and measurements of pressure fluctuations in the turbulent shear layer has been undertaken.

Wave-like large scale eddies have been shown to be the basic characteristic of free turbulent shear flows. For circular jets, measurements of the wave development have been made for the axisymmetric mode of propagation. Recent experiments show that the jet can also support wave propagation in helical modes. Some detail measurements have been performed. A report on the helical mode study was presented at the 10th ICAS Congress in Ottawa, October 1976.

HIGH REYNOLDS NUMBER SUBSONIC FLOW SEPARATION

Model construction and probe construction are now complete. Unfortunately, failure of a sub-miniature pressure transducer has precluded use of fluctuating pitot pressure in the "triple-probe" (referred to in earlier issues of Q.B.). Calibration of the hot/cool wire pair is in the final stages using the 5-in. × 5-in. tunnel.

Experiments in the 5-ft. × 5-ft. tunnel are planned for the end of March, extending into the early part of April. Tests on the basic flat plate turbulent boundary layer will cover a Reynolds number (based on distance from the leading edge) range of 3×10^6 to 1.5×10^8 and a Mach number range of 0.3 to 0.9. The separated flow tests (using a forward-facing step) will be done at three Reynolds numbers up to 1.5×10^8 and at Mach numbers from 0.3 to 0.9. The following summarizes the measurements to be taken:

1. Surface mean and fluctuating static pressure;
2. Mean and fluctuating mass flow rate (wing hot-cool wires);

3. Mean pitot pressure;
4. Skin friction (using obstacle blocks and Laval University balances);
5. Flow visualization.

REYNOLDS NUMBER EFFECTS ON TWO-DIMENSIONAL AEROFOILS WITH MECHANICAL HIGH LIFT DEVICES

A multi-component airfoil model, based on a supercritical airfoil, is being designed. The model will be equipped for pressure measurements on all components and provision is also made for boundary layer – wake surveys in the vicinity of the airfoil surface. The model is part of a program aimed at a detailed analysis of 2-D high lift flow and the effect of Reynolds number on the optimum flap settings.

Work on an iterative solution of the compressible boundary layer flows about multi-element airfoils is continuing at the University of Manitoba.

TESTS IN THE 5-FT. × 5-FT. BLOWDOWN TUNNEL FOR OUTSIDE ORGANIZATIONS

SAAB-Scania, Sweden

Static stability and hinge moment measurements were conducted on a 1/30 scale rigid aircraft model in the transonic Mach number range.

Canadair Limited, Montreal

In the most recent tests of the CL-600 Challenger (formerly Learstar), aircraft, a 1/25th scale model was mounted on a "blade" sting, thus allowing correct representation of the rear fuselage geometry and testing with an empannage, In an effort to provide some information on sting interference effects, the model was designed to allow mounting with the sting blade located on either the top or bottom of the fuselage.

As in the previous tests only force and moment measurements were made for several configurations of the wing, nacelles/pylons, and tail. Some flow visualizations were made for configurations of special interest.

HYDRAULICS LABORATORY

ST. LAWRENCE SHIP CHANNEL

Under the sponsorship of the Ministry of Transport, a study to improve navigation along the St. Lawrence River, using hydraulic and numerical modeling techniques.

NUMERICAL SIMULATION OF RIVER AND ESTUARY SYSTEMS

Mathematical models have been developed to simulate tidal propagation in estuaries, wave refraction in shallow water and littoral drift processes.

DEVELOPMENT OF SPECTRAL ANALYSIS PROGRAMS

For use in the analysis of wave records and on-line analysis of turbulent diffusion data produced in the laboratory.

WAVE FORCES ON OFF-SHORE STRUCTURES

Wave flume study to determine design criteria for off-shore mooring structures.

RANDOM WAVE GENERATION

A study of random waves generated in a laboratory water wave flume by signals from a computer.

MIRAMICHI CHANNEL STUDY

A hydraulic model study to determine the feasibility of deepening the navigation channel of the Miramichi River, N.B. While the hydraulic model study has been completed, a mathematical model is being used to calculate the transport capacities of the upstream section of the estuary. A final report will be available in 1977.

LOCK MODEL STUDY ON VESSEL SIZE

In co-operation with the Marine Dynamics and Ship Laboratory a model study has been undertaken to determine the effect of vessel and lock dimensions on the entrance and exit speeds of ships in locks of the St. Lawrence Seaway.

STABILITY OF RUBBLE MOUND BREAKWATERS

A flume study for the Department of Public Works to determine stability coefficients of armour units and the effect of a number of wave parameters on the stability of rubble mound breakwaters.

WAVE LOADS ON CAISSON TYPE BREAKWATERS

A flume study for the Department of Public Works to determine the overall loading, as well as the pressure distribution on various Caisson-type breakwaters.

WAVE POWER AS AN ENERGY SOURCE

A general study to assess the wave power available around Canada's coast and to evaluate various proposed schemes to extract this energy. International co-operation is taking place through the International Energy Agency of OECD.

PORTSMOUTH HARBOUR MODEL STUDY

A hydraulic model study to investigate wave agitation in Portsmouth Harbour near Kingston, Ont., the site of the 1976 Olympic Marina.

MOTIONS OF LARGE FLOATING STRUCTURES, MOORED IN SHALLOW WATER

A mathematical and hydraulic modeling program will be carried out to develop techniques and methods to forecast motions of, and mooring forces on large structures moored in shallow water.

LOW SPEED AERODYNAMICS LABORATORY

WIND TUNNEL OPERATIONS

The three major wind tunnels of the Laboratory are: the 15-ft. diameter, open jet, vertical tunnel; the 6-ft. × 9-ft. closed jet, horizontal tunnel; and the 30-ft. V/STOL tunnel. During the quarter, 13 programs were undertaken which included work for Canadair Ltd., DeHavilland Aircraft of Canada Ltd. and the Wind Engineering Group of the Laboratory.

WIND ENGINEERING

The construction of a 1:100 scale model of the Olympic Stadium is underway. The aerodynamics of the proposed removable portion of the stadium roof is to be studied. The work is being done for the Olympic Installation Board.

A buffeting analysis of the Lion's Gate Bridge has been completed for Buckland and Taylor Ltd. which predicts stress levels in components of the structure caused by wind turbulence. Aerodynamic data from wind tunnel tests are incorporated into the analysis. A complementary program of measurements of the wind properties and bridge motion has been initiated.

Vortex shedding and galloping response measurements were continued in the 3-ft. × 3-ft. wind tunnel for the 550-ft. high flare stack tower at the La Prade heavy water plant now under construction. A 1:32 scale dynamically mounted model was used. The tests were done for CANATOM-MHG.

FLUIDICS

Co-operative studies with D.G. Instruments of a 3-axis air velocity sensor are continuing using both NRC and industry developed concepts. Studies of vortex excitation of velocity sensor probes have been carried out in co-operation with FluiDynamic Devices Ltd. A program of applications of laminar flow in thin passages is being carried out in co-operation with the Control Systems and Human Engineering Laboratory of DME.

NUMERICAL METHODS

A correlational theory for the prediction of boundary layer transition has been devised and successfully demonstrated in some simple cases which are of interest for the design of airfoils.

The numerical methods are applicable to compressible flows involving heat and mass transfers at the boundaries.

VERTICAL AXIS WIND TURBINE

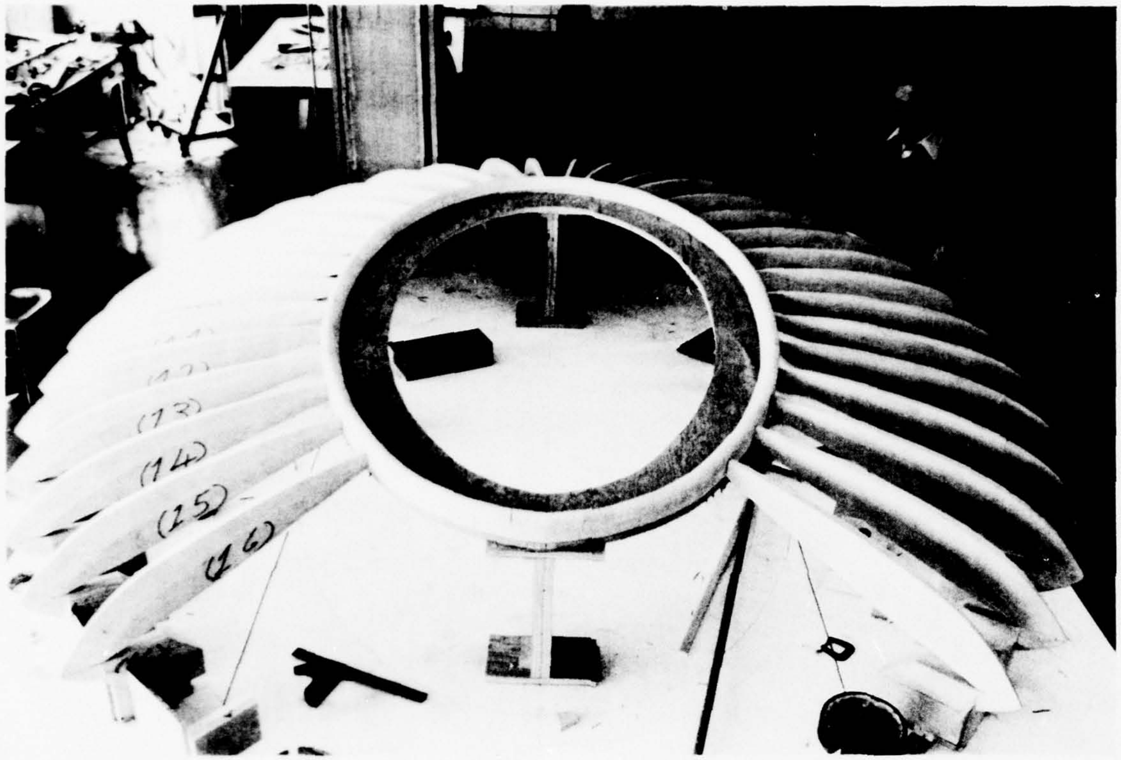
Dominion Aluminum Fabricating Ltd. has delivered six 15-ft. diameter wind turbines to NRC, who in turn has shipped these units to interested federal agencies for field trials. These units are now in operation. DAF are now marketing two sizes (a 15-ft. diameter (4kW) and a 20-ft. diameter (6kW) turbine). Erection of the 200 kW demonstration unit is proceeding at the Magdalen Islands site.

AERIAL SPRAYING OF PESTICIDES

A co-operative program between NAE and the University of New Brunswick, to determine the droplet size distribution of standard nozzle configurations, has been completed. The experimental method consisted of photographing droplets in the 50- to 250-micron range using a narrow depth of focus, and a high intensity flash. An electronic detector was also placed in the spray; its function was to count the number of droplets in a given size range. The second stage of the experiment has been completed with measurements of droplet emissions from a Micronair rotary atomizer being made. Further wind tunnel testing will continue during the latter part of 1977.

A new spray boom design has been tested in co-operation with Conair Aviation (Abbotsford, B.C.). This configuration will have significantly less aerodynamic drag than the present installation which is used on the DC-6B aircraft and is expected to save several hundred horsepower. The spray emission from the new configuration is currently being evaluated in flight.

Theoretical and experimental studies are continuing on the effects of the vortex wake and other factors on the swath width of spray left by a low flying aircraft.



1:100 SCALE MODEL OF THE OLYMPIC STADIUM UNDER CONSTRUCTION FOR AERODYNAMIC STUDIES OF THE REMOVABLE PART OF THE ROOF

LOW SPEED AERODYNAMICS LABORATORY
NATIONAL AERONAUTICAL ESTABLISHMENT

LOW TEMPERATURE LABORATORY

RAILWAY CLIMATIC PROBLEMS

Under the auspices of the NRC Associate Committee on Railway Problems, Sub-Committee on Climatic Problems, a variety of analytical and experimental work is conducted on a continuing basis.

THERMAL PROTECTION OF TRACK SWITCHES

The use of heat to eliminate switch failures from snow and ice is a standard approach to this problem. Work has been carried out on improving the efficiency of forced convection combustion heaters and the means of distributing heat to the critical areas of a switch.

HORIZONTAL AIR CURTAIN SWITCH PROTECTOR

A non-thermal method of protecting a switch from failure due to snow has been undergoing development and evaluation. This method consists of high velocity horizontal air curtains designed to prevent the deposit of snow in critical areas of a switch. The tests conducted to date are especially encouraging with respect to yards and terminals. Additional evaluation is required for the line service application.

NEW RAILWAY SWITCH DEVELOPMENT

The ultimate solution to the existing problem of snow and ice failure of the point switch would appear to be replacement by a new design that is not subject to failure in this way. A switch has been designed, fabricated, laboratory tested and has now completed one winter season of field trials. The design involves only shear loading from snow and ice.

LOCOMOTIVE SANDING EQUIPMENT

An investigation into the various possible modes of failure of a locomotive sanding system resulting from low temperature has been undertaken. In addition to the expected failures resulting from moisture freezing in various parts of the pneumatic equipment, two other modes of failure are being investigated further.

HELICOPTER DE-ICING

A study of helicopter icing protection involving the evaluation of various systems (thermal, fluid, and self-shedding materials) and the development of de-icing control systems including ice detectors. The principles for a dynamic ice detector with high sensitivity to be used on helicopters are being investigated. Investigation of methods of establishing a rate function with the dynamic icing detection principle is being conducted.

MISCELLANEOUS ICING INVESTIGATIONS

Analytical and experimental investigations of a non-routine nature, and the investigation of certain aspects of icing simulation and measurement.

TRAWLER ICING

In collaboration with Department of Transport, an investigation of the icing of fishing trawlers and other vessels under conditions of freezing sea spray, and of methods of combatting the problem.

AIR CUSHION VEHICLE ENVIRONMENTAL PROBLEMS

A study has been started on the deposition of snow on sections representing possible tracks for guided ACV's. Snow and ice deposits are being measured and recorded during each winter storm.

A study of snow removal by unconventional methods is being undertaken for high speed transit systems.

AIRBORNE SNOW CONCENTRATION

To provide statistical data on the airborne mass concentration of falling snow in order to define suitable design and qualification criteria for flight through snow, measurements of concentration and related meteorological parameters are being made.

SEA ICE DYNAMICS

Analytical and experimental work on the techniques of forming low-strength ice from saline solutions is being carried out in connection with proposed modeling studies of icebreaking ships and arctic port facilities.

MARINE DYNAMICS AND SHIP LABORATORY

HIGH SPEED CRAFT

Several models in a systematic series have been studied and others are being prepared to determine their performance in still water and in waves.

YACHTS

A program of sailing yacht model studies is underway using equipment and techniques developed in the laboratory.

BULK CARRIER

A model of a dry cargo vessel was constructed in the laboratory and a careful investigation made to determine the feasibility of its unique design. A new bow, for additional study, is to be manufactured and fitted on the model.

FOIL PROGRAM

An experiment program is to be conducted on a model of a hydrofoil main foil, for which program a special dynamometer has been built by the laboratory.

HYDROFOIL DESIGN SERIES

A series of five hydrofoil models is being considered and two have been built for investigation of their hull lift and drag, foil lift and drag seakeeping.

BEHAVIOUR OF SHIPS IN LOCKS

Three-radio controlled Great Lakes cargo vessel models with varying length beam ratios have been built in the laboratory. A study of their behaviour is being carried out in a Seaway lock model in co-operation with the Hydraulics Laboratory. Investigation is being made of the hydrodynamic forces acting on the vessels during approach and passage through the locks with a view to recommending modifications to the existing lock structures. Full-scale measurements are to be made on board a ship in the near future.

BULB NOZZLE

A model of a bulb nozzle has been built in the laboratory and its effectiveness, independent of the ship's hull, is being analyzed.

Y-PASS SYSTEM

A model, equipped with a Y-Pass system, is being manufactured in the laboratory for evaluation of its performance.

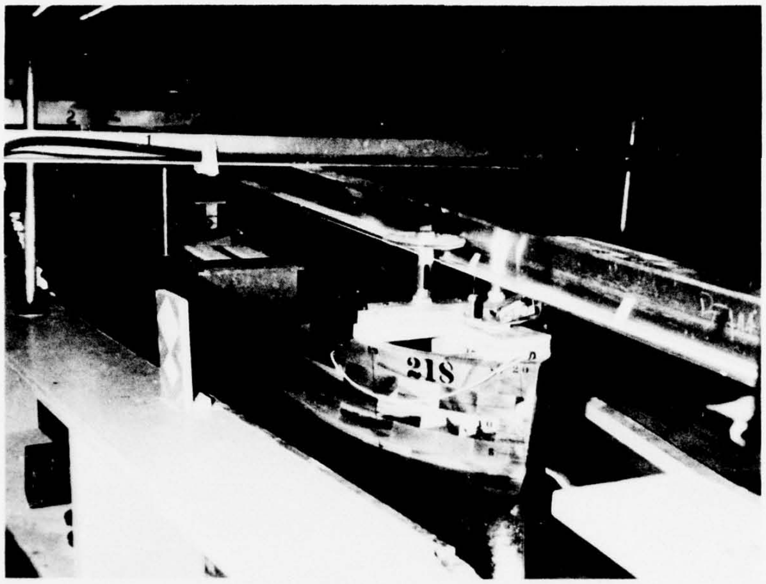
DRILL SHIP

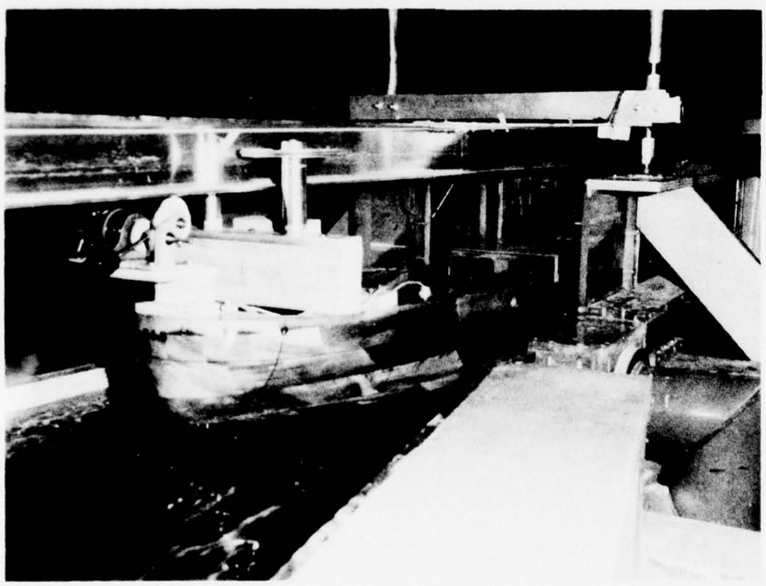
Using a drill ship model, a study has been made in the laboratory of the hydrodynamic aspects of the problem of operating the ship in shore-fast ice by keeping an area around the ship ice-free using the waste heat from the drilling engines.

The thermodynamic aspects of the problem have also been investigated, using one section of the ship, in the ice of the laboratory's outdoor manoeuvring basin.

DEVELOPMENT OF SYNTHETIC ICE

Extensive studies are being carried out, of the physical characteristics and procedures of manufacture of synthetic ice for ship model experiments.





BOW AND STERN VIEWS OF SHIP ENTERING MODEL LOCKS

MARINE DYNAMICS AND SHIP LABORATORY

DIVISION OF MECHANICAL ENGINEERING

RAILWAY LABORATORY

RAILWAY STUDIES

In conjunction with CP Rail, test were carried out to ascertain the drop in pressure in the brake line due to leakage at low temperatures.

Two experimental axles with spin controlled geometric properties have been manufactured and will be tested under a 100-ton grain car at the Uplands test centre in the near future.

The dynamometer car supplied by CP Rail for use as a mobile instrument car has been modified. The pocket to contain the coupler and draft gear is being modified.

The Laboratory has provided assistance to the Canadian Government in the assessment of the performance of passenger trains at high speed. Tests carried out by the American Railroad Passenger Corporation (AMTRAK) on several vehicles were observed and reported.

A transducer to measure surface movement of wheel over rail is being developed.

RAILWAY DYNAMICS BUILDING (U-89)

Level parallel support beams have been laid in the floor of the new building. The concrete floor has been poured around them. An acoustically insulated control room has been erected for viewing and controlling tests on the vibration and roller rigs and for collecting test results.

The vibration stands have been designed and the hydraulic power supply purchased for the building. Delivery of the actuators will be completed shortly. Design of the rail structure to support vehicles in the building has been completed.

Rooms and services have been erected to house the electric power plant to the roller and vibration rigs. This complex includes a small workshop.

Dynamometers are being connected to a pair of roller rig electric motors to aid in the development of their controls. A hybrid computer model has been developed in conjunction with the Analysis Laboratory.

Hardware for the roller rig is being developed and made by the Manufacturing Technology Centre. A design for the position controls has been carried out in the Railway Laboratory.

GENERAL INSTRUMENTATION

The laboratory is co-operating with the Marine Dynamics and Ship Laboratory in the development of the micro-processor controlled ship motion analyzer.

MECHANICAL AIDS TO THE HANDICAPPED

A pocketbook page turner has been developed; a Canadian manufacturer has made three and will make ten more. Evaluation is continuing at two institutions.

NON-CONTACTING LEVEL GAUGE

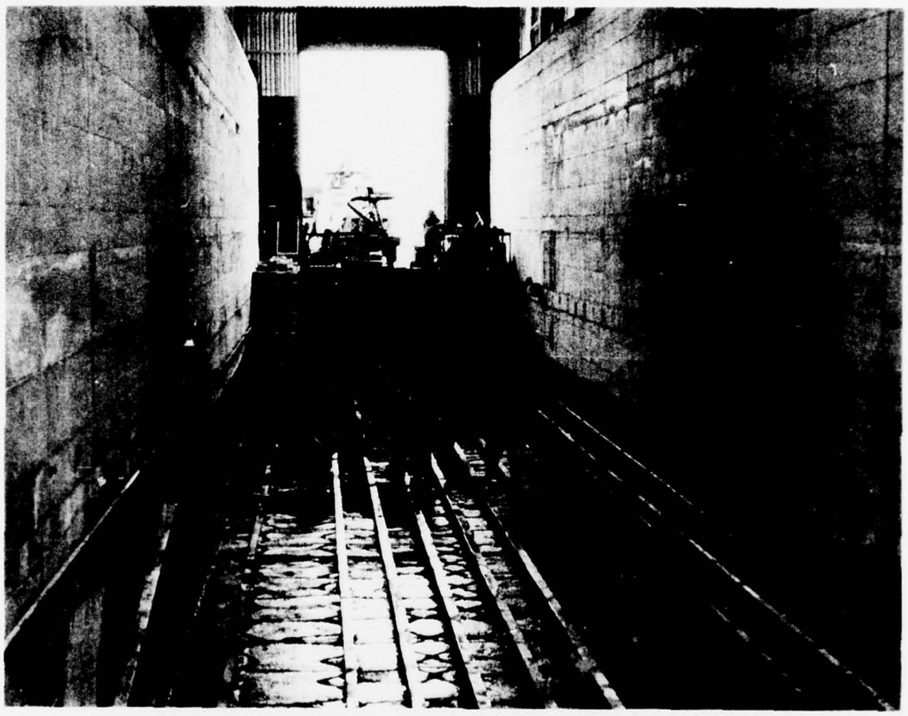
Development of a non-contacting servo gauge using stepping motor drive for the measurement of tidal levels in hydraulic models.

MEDICAL AIDS TO SURGERY

Continued technical support to two local hospitals in the use of prototype and commercial vessel suturing instruments for clinical surgery, and to their Departments of Experimental Surgery in organ transplant procedures, arterio-venous surgery, etc.

A new form of driving mechanism devised to give reduced actuating forces on the larger sizes of vessel suturing instruments has proven effective in experimental surgery.

Assistance to Control Systems and Human Engineering Laboratory in the manufacturing of electrodes to improve the recording of electrospinograms.



BLDG. U-89 – LOOKING EAST DURING POURING OF CONCRETE FOR MACHINERY FLOOR.

STRUCTURES AND MATERIALS LABORATORY

FATIGUE OF METALS

Studies of the basic fatigue characteristics of materials under constant and variable amplitude loading; fatigue tests on components to obtain basic design data; fatigue tests on components for validation of design; studies of the statistics of fatigue failures; development of techniques to simulate service fatigue loading.

RESPONSE OF STRUCTURES TO HIGH INTENSITY NOISE

Study of excitation and structure response mechanisms; study of panel damping characteristics and critical response modes; investigation of fatigue damage laws; industrial hardware evaluation; investigation of jet exhaust noise.

OPERATIONAL LOADS AND LIFE OF AIRCRAFT STRUCTURES

Instrumentation of aircraft for the measurement of flight loads and accelerations; fatigue life monitoring and analysis of load and acceleration spectra; full-scale fatigue spectrum testing of airframes and components.

ELECTRON FRACTOGRAPHY

Qualitative determination of fracture mechanisms in service failures; fractographic studies of fatigue crack propagation rates and modes.

METALLIC MATERIALS

Structure-property relationships in cast and wrought nickel-base superalloys. Studies of the consolidation and TMT processing of superalloy powders and compacts by hot isostatic pressing, hot extrusion and upset forging; studies on mechanical properties. Mechanics of cold isostatic compaction of metal powders, properties of hydrostatically extruded solids and compacts, extruded at pressures up to 1600 MN/m^2. Studies of the oxidation/hot corrosion behaviour of coated and uncoated refractory metals and superalloys.

MECHANICS AND THEORY OF STRUCTURES

Stresses in multi-cell caissons for marine structures. Stress concentrations at corners of box structures. Behaviour of plates under high-speed impact, with reference to bird resistance of aircraft windshields.

FLIGHT IMPACT SIMULATOR

Simulator developed and calibrated to capability of accelerating a 4-lb. mass to velocity of 1000 ft./sec. and an 8-lb. mass to velocity of 760 ft./sec.; operation on year-round basis achieved and includes use of temperature controlled enclosure from $-40°$ to $+130°$F; in addition to airworthiness certification program includes assessment of resistance to impact for materials and structural design for most types of viewing transparencies.

CALIBRATION OF FORCE AND VIBRATION MEASURING DEVICES

Facilities available for the calibration of government, university, and industrial equipment include deadweight force standards up to 100,000 lb., dynamic calibration of vibration pick-ups in the frequency range 10 Hz to 2000 Hz.

COMPOSITE MATERIALS

Studies of composites including resins, crosslinking compounds, polymerization initiators, selection of matrices and reinforcements, application and fabrication procedures, material properties, and structural design.

FINITE ELEMENT METHODS

Development and application of finite element methods to structural problems. Development of refined elements with curved edges. Development of methods for non-linear problems.

MOTOR VEHICLE SAFETY

The mathematical model of the redirection of a vehicle by a cable barrier has been validated experimentally and effort is now being concentrated on the development of a facility for the dynamic measurement of the inertial properties of automobiles by suspending them on air bearings. Engineering charts for the design of flexible road barriers are being prepared.

In collaboration with Ministry of Transport, Road and Motor Vehicle Traffic Safety Branch, studies to determine the performance of headlights in the driver passing task are being carried out. Work is continuing on a system for studying driver performance and traffic quality by the analysis of automatically recorded vehicle control input and response data.

POLICE EQUIPMENT STANDARDS

The NRC/CACP Technical Liaison Committee on Police Equipment is a bilateral arrangement for bringing together police and government personnel to review police equipment requirements, equipment performance specifications, and conformance testing procedures. Work of the Committee is expedited by a permanent Secretariat which has a primary responsibility for continuity in the activities of a number of Sections, each dealing with a particular area of expertise, and for co-ordinating work and specialist contributions from various participating Departments and organizations.

UNSTEADY AERODYNAMICS LABORATORY

DYNAMIC STABILITY OF AIRCRAFT

Development of new techniques for dynamic stability experiments.

Determination of cross-derivatives on an aircraft-like configuration at high angles of attack.

Exploratory measurements of vertical acceleration derivatives.

Development of an electro-mechanical calibrator for the existing dynamic cross-derivative apparatus.

ATMOSPHERIC DISTRIBUTION OF POLLUTANTS

Analysis of the downwind vertical spread of gaseous and aerosol pollutants from sources near the ground, with special emphasis on the effect of atmospheric stability.

Instrumentation of a small mobile laboratory to measure airborne particulates and of an aircraft to detect atmospheric tracers.

Use of the above detection system to measure the vertical spread of a pollutant in a polar atmosphere during the AES pilot study of polar meteorology on Lake Simcoe.

TRACE VAPOUR DETECTION

Development of highly sensitive gas chromatographic techniques for detection of trace quantities of vapours of pesticides, explosives and fluorocarbons.

Sensitivity evaluation of commercially available explosive detectors.

Airborne and ground-vehicle based measurements of the spread and distribution of various aerosols and tracer gases.

Development of techniques for conditioning and testing of biosensors.

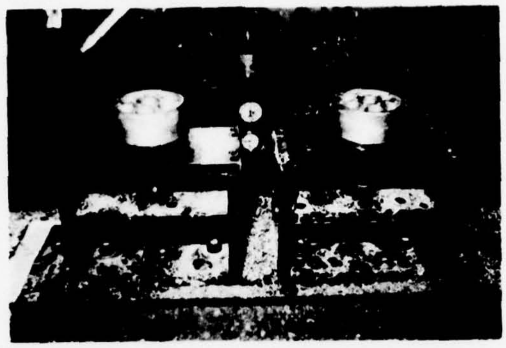
WORK FOR OUTSIDE ORGANIZATIONS

Dynamic moment measurements and flow visualization studies for NASA, using wind tunnel facilities at NAE and at NASA Ames.

Feasibility and design studies for NASA.

Aircraft-security feasibility studies for Transport Canada.

Scientific assistance to interdepartmental Explosives Detector Evaluation Program, Montreal.



TWO-PART FIXTURE
5-TOOL CHANGES
MACHINING CYCLE TIME: 7 MIN.

MULTI-PART FIXTURE
5-TOOL CHANGES
MACHINING CYCLE TIME: 22 MIN.
TIME SAVED PER PART: 45 SEC.

WESTERN LABORATORY (VANCOUVER)

PRACTICAL FRICTION AND WEAR STUDIES

Laboratory simulations of practical sliding contact and bearing conditions to obtain the friction and wear characteristics of lubricants and materials. Recent projects undertaken in response to specific external requests have included:

Measurement of the friction and wear behaviour of a glass fibre reinforced plastic (PTFE) material and assessment of its suitability for bearing pads on hydroelectric dam diversion gates.

Investigation of seizures in marine hydraulic steering gear components at low ambient temperatures.

In addition extensive modifications to the thrust washer test rig have been carried out to permit operation up to about 900°C.

FUNDAMENTAL STUDIES IN TRIBOLOGY

Continuing investigations of friction and wear processes in general including initiation of studies of friction and wear in some non-metallic materials.

LUBRICANT ANALYSIS

Analysis of used marine oils to assess their degree of deterioration as an aid to the prevention of engine failures.

PRACTICAL STUDIES OF BEARINGS AND SEALS

Design of a machine to test the effectiveness of the lubrication system of locomotive traction motor support (journal) bearings at low temperatures.

Design and construction of a static model of a vane in a ship's hydraulic steering gear to assess the effect of changes in seal materials and design on leakage.

INSTRUMENTATION STUDIES

Continued development of a photoelectric automatic bus passenger counting system, in particular the utilization of a distributed light source.

The numerical control (NC) editor program, NCEDIT, (Report LTR-IN-300) has been modified and expanded. Testing has been completed and the new version is now in use in the Western Laboratory.

A memory protect function has been constructed and added to the Western Laboratory mini-computer system and a semi-conductor memory expansion has been designed and built. An additional interface between this memory and a micro-processor is now under test.

Instrumentation has been developed for the Division of Building Research for the automatic tape recording of velocity and pressure measurements in snow avalanches in the Rogers Pass near the Trans-Canada Highway. This equipment has been in use over the past winter months.

NUMERICALLY CONTROLLED MACHINING

Technical assistance on this subject is being provided to firms and other institutions in Western Canada which are considering the purchase of numerically controlled machines to improve their production efficiency. Seminars are held to explain the fundamentals of numerical control and programming and the laboratory's three-axis NC milling machine is used to machine demonstration batch quantitites of typical components for interested companies.

The preceding illustrations show a recently demonstrated example of multi-part NC fixturing. Five-tool changes are required to machine the part shown. Machining cycle time is reduced by six minutes when each tool is called for once to machine eight parts instead of two parts.

PUBLICATIONS

AERONAUTICAL REPORTS

LR-594 ANALYSIS OF WALL INTERFERENCE EFFECTS ON ONERA CALIBRATION MODELS IN THE NAE 5-FT. × 5-FT. WIND TUNNEL.

M. Mokry, R.D. Galway, National Aeronautical Establishment, March 1977.

The measurements on three geometrically similar aircraft models by ONERA are used to analyse lift interference effects in the solid and perforated wall test sections of the NAE 5-ft. × 5-ft. test facility. The prediction of the angle of attack correction for both test sections is based on the representation of the model by lifting lines and the solution of the subsonic wall interference problem by the finite difference method. The value of the porosity factor ascribed to the test section with perforated walls is checked by comparing the measured wall pressure distributions with the theoretical ones, predicted by the present method. The lift interference effects on models M1 and M3, having wing span to wind tunnel width ratios of 0.188 and 0.311 respectively, were found to be within the limits of experimental errors. For the M5 model, having a wing span to wind tunnel width ratio of 0.644, the solid and perforated test section measurements, corrected using a uniform angle of attack correction, show good agreement up to lift coefficients of about 0.5. At higher values of the lift coefficient, the effects of the spanwise variation of the angle of attack correction in the solid wall test section become more significant, as demonstrated by measured pressure distributions at three spanwise locations of the wing. Based on the theoretical prediction, the test section with 20.5% perforated walls produces a more uniform distribution of the angle of attack correction along the wing span, and hence should yield more reliable test data than the section with solid walls.

MECHANICAL ENGINEERING REPORTS

MH-111 WAVE LOADS ON LARGE CIRCULAR CYLINDERS: A DESIGN METHOD.

G.R. Mogridge, W.W. Jamieson, Division of Mechanical Engineering, December 1976.

The forces and overturning moments exerted by waves on large vertical circular cylinders have been measured in the laboratory. Two rigid cylinders, 12 in. and 26.5 in. in diameter, extending from the bottom of wave flume through the water surface, were tested in varying depths of water, for a range of wave periods and wave heights up to the point of breaking. A digital computer was used for the acquisition, processing, plotting and storage of the experimental data.

In addition to the experimental work, a design method is presented which allows the wave loads on large circular cylinders to be estimated by means of a simple desk calculation. The experimental data shows that this simple method of calculation, based on the linear diffraction theory of MacCamy and Fuchs, is accurate over a wide range of wave conditions and cylinder sizes.

MS-139 A PARAMETRIC STUDY ON HIGHWAY CABLE BARRIER PERFORMANCE AND ITS EFFECT ON VEHICLE REDIRECTION DYNAMICS.

G.L. Basso, National Aeronautical Establishment, February 1977.

A parametric study of the highway cable barrier system and its effect on vehicle redirection has been carried out using the NRC barrier analysis, as programmed for digital simulation in conjunction with an existing analysis of the vehicle-terrain system. Component data sets were obtained from barrier experimental measurements and a vehicle parameter study.

A two-part study was performed. The initial phase dealt with barrier response. An evaluation of the effect of design parameters on design response variables was conducted. The importance of post parameters was highlighted. A means of using these characteristics to improve performance was considered. A brief extension of the analysis to other tension barrier systems has also been included.

The second phase considered vehicle interaction with cable barriers, straight and curved, over level and sloping terrain. To do this, system components were chosen so as to represent typical upper and lower bound combinations for the private passenger class of automobiles. A number of computer tests were performed with the object of evaluating vehicle response of performance as affected by critical barrier and terrain parameters. Correlation with such parameters was established for purposes of mapping bounds of acceptable vehicle performance. The most dominant instability found to occur was a vehicle roll-over condition.

LABORATORY TECHNICAL REPORTS

National Aeronautical Establishment

LTR-FR-57 Daw, D.F.

Tests of a Reverse Flow Outside Air Temperature Probe for Use on Cloud Physics Research Aircraft.
January 1977.

LTR-FR-59 Drummond, A.M.

Effects of Aerodynamic Interference on the Atmospheric Environment Service Particle Measuring Devices Mounted on the NAE Twin Otter.
February 1977.

LTR-LA-197 Williams, C.D., Wardlaw, R.L.

Further Measurements of Arch Hangar Vibrations on the Burton Bridge.
September 1976.

LTR-LA-198 Williams, C.D., Wardlaw, R.L.

Wind Tunnel Investigations of Smoke Stack Performance for an Oil Tanker.
February 1977.

LTR-LA-203 Cooper, K.R.

Wind Tunnel Tests on a V.O.R. Field Detector for Philips Electronics.
October 1976.

LTR-LA-204 Cooper, K.R.

Wind Tunnel Investigations of Aerodynamically Induced Structural Vibrations of an Aerial Towed Body for Hudson Bay Mining and Exploration.
October 1976.

LTR-LA-207 An Investigation of the Aerodynamics Drag of Spray Boom Configurations on Conair DC-6 Aircraft.
January 1977.

LTR-LA-212 Irwin, H.P.A.H.

A Wind Tunnel Investigation of the Proposed St. Johns River Bridge, Jacksonville, Florida.
January 1977.

LTR-LA-213 Williams, C.D., Wardlaw, R.L.

Wind Tunnel Investigation of Smoke Stack Performance for the Polar VII Ice Breaker.
February 1977.

LTR-UA-41 Orlik-Rückemann, K.J.

Dynamic Stability Testing in Wind Tunnels.
March 1977.

Division of Mechanical Engineering

LTR-CS-162 Schwartz, J.-L.

Experimental Apparatus for Voltage-Clamp Experiments on the Lobster Giant Nerve Fibre Under Constant Magnetic Field Exposure.
January 1977.

LTR-CS-163 Gellie, R.W.

Cross Assembler for the M6800 Microprocessor.
February 1977.

LABORATORY TECHNICAL REPORTS (Cont'd)

Division of Mechanical Engineering (Cont'd)

LTR-CS-164 Gellie, R.W.

PDPM68 Object Code Formatter for M6800 Microprocessor.
February 1977.

LTR-CS-165 Gellie, R.W.

CAMAC Handler.
March 1977.

LTR-CS-167 Gellie, R.W.

CAMAC Special Fortran Subroutines.
March 1977.

LTR-ENG-54 Krishnappa, G., Rimmer, R.J., Hammell, T.H.

The Effect of an Extended Circular Casing on the Aerodynamic and Acoustic Performance of a 15 Horse-power Blower.
December 1976.

LTR-HY-58 Pratte, B.D.

Flow Resistance Due to Reconsolidated Ice Covers.
October 1976.

LTR-WE-1 Whale, K.G.

NCEDIT-II Numerical Control Editor Users Guide.
January 1977.

LTR-WE-2 Hawthorne, H.M., Lau, R.

Laboratory Assessment of Glass Filled PTFG as Bearing Pad Material for Diversion Gates.
February 1977.

LTR-WE-3 Hawthorne, H.N., Lowe, J.

Marine Hydraulic Steering Gear Component Testing.
February 1977.

TECHNICAL TRANSLATION

TT-1891 HOT FORGING OF A HEAT-RESISTANT FIBROUS COMPOSITE MATERIAL
* $2.20

KUZNECHNO-SHTAMPOVOCHNOE PROIZVODSTVO, (6): 18-20, 1975

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* The above translation is available from the Translation Section, NRC Library, Sussex Drive, Ottawa, Ontario, either on an exchange basis with libraries of Government departments and universities or at the price indicated.

MISCELLANEOUS PAPERS

Buck, L. Circadian Rhythms in Step-Input Pursuit Tracking. Published in Ergonomics 1977, 20, pp. 19-31.

Chan, Y.Y. Noise Generated Wavelike Eddies in a Turbulent Jet. ICAS Paper 76-42, The Tenth Congress of the International Council of the Aeronautical Sciences. October 1976.

Chan. Y.Y. Spatial Waves of Higher Modes in an Axisymmetric Turbulent Jet. The Physics of Fluids, Vol. 19, No. 12, December 1976, p. 2042.

Gellie, R.W. Computer Control Standards Part 1: Computerized Process Control and the Search for the Perfect Interface. Canadian Controls and Instrumentation, December 1976 - January 1977, pp. 34-35.

Gellie, R.W. Computer Control Standards Part 2: Computerized Process Control and the Interface. Canadian Controls and Instrumentation, February 1977, pp. 30-32.

Hanff, E.S., Orlik-Rückemann, K.J. Wind-Tunnel Test and Calibration Techniques for the Measurement of Damping and Dynamic Cross-Derivatives due to Pitching and Yawing. Presented at the 15th Aerospace Sciences Meeting, Los Angeles, California, 24-26 January 1977. AIAA Paper 77-80.

Kekez, M.K., Savic, P. A Study of Breakdown Delay in Electrically Pumped Laser Gases. Can. J. Phys. 55, 325, 1977.

Krishnappa, G. Some Experimental Studies on Centrifugal Blower Noise. Proceedings of INTER-NOISE 77, March 1977.

Lindberg, G.M., MacNaughton, J.D.* Remote Manipulator System and Satellite Servicing Experiment for Space Shuttle. Paper presented at the AAS/DGLR International Meeting on the Utilization of Space Shuttle and Spacelab, Bonn, West Germany, June 2-4, 1976. To be published in the Proceedings.

Orlik-Rückemann, K.J. On Aerodynamic Coupling Between Lateral and Longitudinal Degrees of Freedom. Presented at the AIAA 15th Aerospace Sciences Meeting, Los Angeles, California, 24-26 January 1977. AIAA Paper 77-4.

Pinkney, H.F.L., Ayad, A.A., Huculak, P., Harrison, A.L. A Systems Engineering Study of Night Visibility with Automobile Headlighting. Paper presented at Society of Automotive Engineers, International Automotive Engineering Congress and Exposition, held in Detroit, Mich., March 1-4, 1977. Published under SAE No. 770240.

Wallace, W. Discussion Summary of Session II. AGARD Conference Proceedings No. 200 on Advanced Fabrication Techniques in Powder Metallurgy and their Economic Implications, p. DS2-1 to DS2-2. Conference held in Ottawa, April 1976.

Wallace, W., Immarigeon, J-P., Trenouth, J.N., Powell, B.C.** Control of Grain Structure during Superalloy Powder Processing. AGARD Conference Proceedings No. 200 on Advanced Fabrication Techniques in Powder Metallurgy and their Economic Implications, p. P9-1 to P9-13. Conference held in Ottawa, April 1976.

UNPUBLISHED PAPERS

Johnson, R.R., Ploeg, J. The Problems of Defining Design Wave Conditions. Ports '77 Conference, Los Angeles, California, March 1977.

Lane, J.F. Recent Research in Snow Removal Techniques at N.R.C. Presented at a meeting of the International Society for Terrain Vehicle Systems, Hanover, N.H., 23-25 February 1977.

Ohman, L.H. NAE Contributions to the Development of Supercritical Airfoils and Jet Augmented Airfoils. Lecture presented at a CASI meeting on March 8, 1977.

Ploeg, J. The Potential of Waves and Tides as a Source of Energy. Seminar presented at Carleton University, Ottawa, March 24, 1977.

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Books received			32
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